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CHARACTERISTICS OF OPTICAL FIRE DETECTOR FALSE ALARM SOURCES AND QUALIFICATION TEST PROCEDURES TO PROVE IMMUNITY, PHASE II, VOL I

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This study identified possible sources of UV, IR and visible radiations that may cause an optical fire detector to false alarm and/or affect its fire detection performance. The spectral irradiances of JP-4 pan fires and a multitude of lamps, hot bodies, and other of radiation stimuli that an optical detector may be exposed to in any type of aircraft shelter, hanger, facility, or ground location, were determined. Knowing the spectral irradiances of the required fire size and distance to be detected, it was then possible to determine at what distances would the potential false alarm source have to be to equal or exceed the fire's spectral irradiances in the 185nm - 250nm and 4.41m bands. Considering the possible distance from detector to source, candidate false alarm sources were selected for detector immunity testing. Qualification test procedures were developed and tested. It was concluded that there are many possible false alarm sources and, if located too close to a detector, and the stimuli are modulated, most optical fire detectors would alarm.

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PREFACE

This final report was prepared by Donmar Limited, 901 Dover Drive, Suite 120, Newport Beach, California 92660, under Contract F08635-91-C-0129, with Wright Laboratory, Fire Protection Section (WL/FIVCF), Tyndall AFB, FL 32403-5323.

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EXECUTIVE SUMMARY

A. OBJECTIVE

The objectives of this project were: (1) to determine the nature and properties of objects and phenomena that may cause an optical fire detector to false alarm and/or affect its ability to identify fire; and (2) to develop qualification test procedures to determine an optical fire detector's false alarm immunity.

B. BACKGROUND

It was assumed that the minimum detection threshold of a detector must be at least equal to the spectral irradiance from the specified type and size fire at its specified maximum distance from the detector. The fire type, size, and distance assumed herein for analysis was the standard Air Force specification of a 2-foot x 2-foot JP-4 panfire at a distance of 100' in 5 seconds or less (or a 1-foot x 1-foot at 50 feet). Spectral irradiance data were measured during controlled burns.

C. SCOPE

Consideration was given to both monospectral detectors (e.g. UV, IR, visible) and multispectral detectors (e.g. UV/IR and other combinations of the EM spectrum) in this study. The bands where most of these detectors operate are 185nm-250nm centered at about 220nm in the UV, and about 4.2μm-4.6μm centered at 4.4μm in the IR.

Possible false alarm sources were identified by analyzing past events, reviewing Air Force bases in the U.S. and Europe, discussing false alarm problems with detector manufacturers, and analyzing objects and phenomena that may exist in the field-of-view of a detector when used in various applications. Spectral irradiances were then determined by field measurements concentrated at Edwards AFB, laboratory measurements, and literature reviews. These spectral irradiances were then compared to the measured spectral irradiances in the same bands of the 2-foot x 2-foot JP-4 fire at 100 feet. Sources were selected that either individually or in combination had sufficient irradiances to satisfy what should be the minimum thresholds of an optical fire detector in its band(s) of operation. Manufacturers were asked to supply detectors set at the above threshold level. These were used to develop test procedures for the false alarm sources that may be found in any typical Air Force hangar, shelter, or facility. Distances between source(s) and detector were determined for practical applications.

D. CONCLUSION

It was concluded that many types of UV and/or IR sources can satisfy the minimum energy flux threshold of a fire detector commonly used in AF hangar and shelter applications. The nature

and properties of these sources were identified in great detail in this study. Moreover, although most detectors today use other features in their detection logic, such as modulation of the incoming IR signal or ratioing of two wavelengths, all these features can be and have been duplicated during routine aircraft-associated ground operations.

E. RECOMMENDATION

This study resulted in a recommendation of a set of test procedures that can be included in an RFP, a purchase description, or a specification to help assure that the detector(s) being purchased meet the reliability expectation of the government before delivery and installation.

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SECTION I

INTRODUCTION

A. OBJECTIVES

The overall goal of this program was to improve the reliability against false alarms of fire detectors used in military aircraft hangars, shelters, and facilities, and during military operations. To satisfy this goal a better understanding is necessary of the nature and properties of possible sources of nonfire radiation stimuli which may be mistakenly interpreted by a detector to emanate from the specified fire event, even though a fire is not present.

Such mistaken interpretations can also result in erroneous release of fire-suppressant agent. Knowing the emission characteristics, however, of such nonfire objects and phenomena, a detector's response can be predicted for any sensitivity level to which it is set to detect a specified type of fire, at a specified distance, in a specified maximum time (e.g., a 2-foot x 2-foot JP-4 pan fire at a distance of 100 feet in 5 seconds or less after the fire has reached this size). Corrective actions or precautions can then be taken by either the detector manufacturer and/or the government user agency.

The specific objectives of this program were threefold: (1) to identify possible sources of nonfire radiation stimuli that may cause a fire detector to falsely alarm, (2) to determine the physical characteristics of these possible "false alarm sources", such as their spectral irradiance, and (3) to develop qualification test procedures to determine a detector's immunity/response to the presence of these objects and phenomena.

With such information, a government agency can specify certain test procedures to be performed by the manufacturer on its detector to verify that it will not false alarm to the nonfire radiation stimuli to which it would be exposed in its application. On the other hand, knowing that a detector will respond to certain types of false alarm sources at some distance from the detector would be useful to the government user agency (or purchasing agency). The agency could either decide not to deploy these types of false alarm sources within the facility/hangar, separate them at a greater distance from the detector to reduce the irradiance at the detector to an acceptable level, or to accept the fact that false alarms will occur unless the fire protection system is deactivated when these sources (including operations and phenomena) are present. If the latter option is taken, the objective of providing continuous fire protection coverage, a major weapon system for example, may be defeated.

Performance of qualification tests on detectors being considered for acquisition and deployment would then be beneficial to both the government and to the detector industry. Verification of such false alarm immunity in advance of a detector's purchase/acquisition would provide a means to assure the user agency of a reliable fire detection system, and one that is in compliance to the performance, reliability, and quality specification.

Industry would benefit by knowing the government's requirements and the characteristics of the nonfire sources of radiation stimuli. Detectors could therefore be modified/designed to be more discriminating to such nonfire sources, thus increasing the reliability of fire detection technology.

B. BACKGROUND

Commercial grade fire detectors used in military aircraft hangars, aircraft shelters, and facilities, measure one or more of the ultraviolet, infrared, and visible emissions from a fire event to discern its presence. The intensity of these radiations is used as a criterion to estimate the fire's size at some distance, although due to the $1/r^2$ law it is impossible for such a detector to determine actual size, location, or even direction unless the detector functions in the video/image processing mode.

Hydrocarbon fires, such as aircraft fuel fires (e.g., JP-4 or JP-8), have broad wavelength band emissions across the ultraviolet, visible, and infrared portions of the electromagnetic spectrum. However, there are certain discrete emission characteristics such as the CO^2 emission "spike" near 4.4 micrometers. Also, because the atmosphere absorbs most solar radiation in the 185 nm - 240 nm ultraviolet band, the relatively low level of ultraviolet emitted by hydrocarbon fires in this band (as compared to the IR emission at 4.4 μm) can be distinguished above the background solar radiation. For these reasons, most commercial grade fire detectors operate in the 185 nm - 260 nm ultraviolet band and in the 4.2 μm - 4.7 μm infrared band.

Unfortunately, many nonfire sources also emit/radiate radiation in these UV and IR bands. Some of these emit sufficient energy flux to satisfy a fire detector's set threshold, thus false alarming and/or causing a false activation of the fire-suppressant system.

To provide more discrimination capabilities in their detectors, some detector manufacturers have added additional detection logic. This includes requiring the measured infrared radiation to vary in frequency between 1 Hz and 10 Hz (referred to as "flicker" or "chopping"). Another added detection discriminant is the

requirement for the ratio between the IR irradiance and UV irradiance to be above some level after background has been subtracted. Also, as a means to reduce sensitivity to false alarms, electronic time gates are often used, but these result in delaying the fire detection time. There are other discriminant approaches that add specificity to fire detection vs. false alarm detection. In some instances, however, the use of some discriminants also make it difficult for the detector to "see" a fire when certain nonfire UV and IR sources are present.

The results of a Phase I feasibility study (Reference 1) substantiated the occurrence of fire detector false alarms and false activations of fire protection systems and the need to determine the nature and properties of the sources of stimuli that cause such false alarms. Visits to Air Force bases, discussions with military fire, civil engineering, and aircraft maintenance personnel, and information provided by the detector industry revealed that optical fire detector false alarms are not uncommon, although the causes vary over a wide range. Although the frequency of events has decreased in those cases where old technology UV and IR units have been replaced with UV/IR dual band detectors, they have not been eliminated. This is due in part to the basic nature of UV and IR detector technology and to the fact that there are many nonfire sources of the same fire spectral radiations.

According to HQ AFCESA about 33,000 false fire detections (covers all types of detectors) in Air Force facilities occurred in 1990. In the same year about 500 false activations of suppressant systems were reported. Included in these numbers are those optical fire detector false alarm events which were not documented in detail because no financial loss was involved. At least 50 occurrences of optical UV, IR, and/or UV/IR detector false alarms were reported over the past 2 years.

Examples of other false alarm events not included in archived reports, include National Guard hangars, airport hangars, and several AF bases. At one base location, consecutive false alarms of UV/IR detectors were found to be due to aircraft engine start-ups and other phenomena. The detectors were subsequently disconnected awaiting repair or replacement. At another base, single-band UV detector false alarms were so routine that the fire protection system was turned off.

This study verified the importance and benefits to both supplier and user of defining the characteristics of potential false alarm sources and to develop test procedures to test a detector's immunity. It was further concluded that the performance reliability of fire detectors could be increased if these qualification test procedures were included as part of a government agency's detector procurement performance specification and/or request for proposal/quotation.

During the Phase I study many Air Force bases were reviewed for fire protection system false alarms and activations. Reviews were also made of the types of possible false alarm sources that existed at each base. It was concluded that Edwards AFB had a large contingency of different types of nonfire UV and IR sources, and a large variety of aircraft, hangars, facilities, operations, and burn facilities. It was recommended that Edwards AFB be the focal point for field measurements of the fire and nonfire emission characteristics.

C. APPLICATIONS

The information generated during this study will directly benefit both the Department of Defense and detector manufacturers. In the former case, DOD could realize higher-reliability fire detection systems and reduced numbers of false alarms and false activations of suppressant systems. In the latter case, industry will have definitive information on the spectral emission characteristics of possible false alarm sources which can be used to enhance the false alarm immunity of their detectors.

Both government and industry will also benefit by the qualification test procedures developed herein. These will assure the government before it takes delivery of a detector, that the detectors will meet the false alarm immunity specification included in the purchase description/request for proposal in advance of installation. The procedures will also help industry in their engineering design to give consideration to the performance requirements specified in the qual-test procedures specifications.

Fire detector companies set the sensitivity level of their detectors by various means, including exposing the detector to the specified size fire at the specified distance, and adjusting the sensitivity level until the appropriate "fire" response is obtained. In this manner, a claim can be made that the detector will identify a certain minimum size fire at a minimum distance within a maximum time. Knowledge of the actual spectral irradiance of the fire is not necessary in this approach. Without using radiance information and simulation, the only way to verify that the detector will not false alarm to nonfire sources in its field of view (FOV) is to actually place these sources in the FOV at the distance they will be located in the actual application. This is impossible when considering the multitude of possible nonfire stimuli and the their many possible combinations.

The spectral irradiances of JP-4 fire and false alarm sources measured in this study can be used to determine what sources at what distances equal or exceed the spectral irradiance in the same spectral regions of the specified size fire at the specified distance.

For example, if the fire detection requirement is to detect a

2-foot x 2-foot JP-4 pan fire at 100 feet, and a UV/IR detector is required, the irradiances in the two spectral bands would be known. Comparing these irradiance values with those for the nonfire UV and IR radiation sources that may be located within the detector's FOV will reveal which sources at what distances from the detector would yield sufficient energy flux to be identified as the specified fire event.

By knowing these irradiance values, a selection can be made of what false alarm sources should be included in the qualification tests.

The information included herein will also assist in determining the direction of research for new detector technology that will improve detector performance and increase detector reliability against false alarms. It is apparent that many sources of UV and IR exist within military facilities, especially within aircraft locations. By requiring verification of a detector's performance and immunity to false alarms through qualification testing, the Air Force and other DOD agencies may realize a decrease in false alarms, less interruption of strategic military operations, an increase in overall fire protection system performance and reliability, and more environmental safeguard.

D. SCOPE

The scope of the program included electromagnetic emission characteristics and possible induced environmental effects.

A detector's performance and reliability can also be influenced by environmental factors such as humidity, temperature, vibration, and water immersion, as well as by electromagnetic fields and ionizing radiations such as from nondestructive x-ray testing devices.

Objects and phenomena that may affect a fire detector were identified. Their properties were determined through review of manufacturers specifications and other technical reports, and by laboratory and field measurements.

Spectral emission properties of JP-4 fire were also determined in field measurements. Burns were made at Edwards AFB and at other locations in Southern California.

A contingency of possible false alarm sources, such as lights, was assembled in the laboratory and mounted on mobile fixtures. Detectors were obtained from the fire detector industry, mounted on mobile fixtures, and exposed to these sources in various arrangements that simulated most probable configurations in practical applications. The detectors were used to assist in developing qualification test procedures and no attempt was made at

testing any detector for its fire detection performance or its immunity to these sources. The detectors were useful in understanding how the various nonfire radiation emission sources influenced fire detectors and whether the measured irradiance values of false alarm sources corresponded with detector responses.

The Air Force did not permit the detector manufacturers to witness laboratory tests involving other company's detectors, or to receive any information pertaining to the performance of other manufacturer's detectors. Each manufacturer, however, was verbally informed about any false alarm response made by its detector during the process of developing the qualification test procedures. Not all detectors were used in each developmental test and not all detectors were exposed to the same possible false alarm sources. This study was not a test of the relative performance and classification of one fire detector against another. Care was taken to enclose each detector so that only its window was observable to the experimenters. Detectors were listed by letters corresponding to their type (e.g. UV, IR, UV/IR).

In the process of developing and duplicating test procedures, there were some tests which were impossible to conduct with the exact number and type of sources at the same distances expected in the actual application. Simulations were used where practical. For example a smaller light source may be located at a closer distance to the detector to simulate a larger light source at a greater distance to assure the same spectral irradiance at the detector ("$1/r^2$" dependency).

The recommended test procedures cover the majority of possible scenarios of field operations. They are not all inclusive, however, and should be augmented and expanded as they are applied. The procedures were written in such a manner that a user (buying) agency may only require certain tests to be performed because others are not applicable to the application.

In addition to the irradiance data and test procedures, the program also generated considerable physical properties data on many types of nonfire radiation sources. This "catalog" of reference data is included as an Appendix to this report.

SECTION II

REQUIREMENTS

A. GENERAL REQUIREMENT

A continuing Air Force objective is to improve fire protection technology in general, and fire detectors, suppression systems, and agents in particular.

The fire detector industry provides products that meet its customer's performance specifications/requirements. A detector's performance is usually measured against the requirements stated in a purchase description or technical specification. If it performs according to the stated requirements it is considered to be a "qualified" detector. If for some reason the detector fails or false alarms due to some unstated reason or false alarm source, then the buyer considers the detector to be of "poor" quality and reliability, even though the buyer did not stipulate all the expected performance specifications as part of the purchase description. In other words, the buyer got what he ordered and the supplier developed what he thought was required.

An objective of this effort is to provide the buyer (DOD agency) with information that may assist in identifying specific false alarm sources and proving detector conformance. Knowing the requirements, the manufacturer will develop more qualified and reliable fire detectors to meet the market demand and competition, and the buyer will benefit with fewer false alarms and less interruptions of military operations.

The manufacturer's performance claims are also sometimes restated as required performance factors. In component acquisitions associated with military weapon systems the performance of the component must be demonstrated to conform with the specification as part of the terms and conditions of the purchase contract. Usually, detailed qualification tests are required to be performed according to specified test procedures. Some of these test requirements can be waived if other relative test results can be used in place of the recommended approach. In this manner, some of the performance qualification tests can be satisfied by "qualification by similarity" or "analysis."

Most facility- or hangar-type fire detectors are purchased without detailed performance specifications. Only a few "detection systems" (e.g., B-2 hangars), are acquired through definitive performance and reliability specifications, including some environmental constraints. In most cases where some form of specification was included in the RFP, only a few items were

listed as possible false alarm sources (e.g., sun, lightning, welding).

On the other hand, if the request for quotation is for an optical fire detection system for a military aircraft, tank, or vessel, the list of sources to which the detector must be proven immune is much more inclusive. Reliability is a major consideration.

The two requirements addressed herein include (1) the identification of possible false alarm sources and determination of their physical, temporal, and spatial properties, and (2) the determination of how to prove detector immunity (or response) to these sources under stipulated test procedures.

In order to satisfy these requirements information is needed on (1) the spectral emission properties of fire (herein assumed to be JP-4 fuel or other JP-series hydrocarbon fuels); (2) the spectral operational characteristics of fire detectors; (3) the types of sources of radiations in the wavelength bands where the fire detectors operate; and (4) the spectral irradiance from these nonfire sources in the same bands where fire detectors operate. Once this information is available, test procedures can be developed to test a detector's immunity.

B. REQUIREMENT TO DETERMINE CHARACTERISTICS OF FIRE AND POTENTIAL FALSE ALARM SOURCES

A specific requirement of this program was to measure the spectral irradiance of fire, especially in the wavelength bands which are used in fire detection methods. The basic fire detection specification usually pertains to detecting a certain type of fuel fire contained in a square pan at some distance from the detector within some time after the fire has reached the specified pan size. The greater the distance of the fire the less energy is incident upon the detector, and the more sensitive the detector must be to "see" the fire. The radiated energy flux falls off as the inverse square of the distance, and atmospheric attenuation also further reduces the intensity as a function of distance.

Knowing the spectral irradiance (energy flux in some specified spectral wavelength band per unit area) of the source (fire) at the detector's distance, the possible effect of nonfire potential false alarm sources can be determined by comparing their spectral irradiance with that of the fire at the specified distance.

The two major spectral regions in which fire detectors operate are about 185 nm - 260 nm in the ultraviolet, and about 4.2 μm - 4.7 μm in the infrared. In the ultraviolet band, the atmosphere absorbs most of the background solar radiation so

there is little "noise," although the energy flux from a fire is very low. In the infrared band there is a "spike" of emission near 4.37 micrometers (the CO_2 emission band) which can be easily distinguished over the broad blackbody-type of background fire emission curve.

The spectral irradiance of fire and possible false alarm sources were therefore measured in these bands. A review of the literature was unsuccessful in identifying any pan fuel fire irradiance measurements in these bands. Irradiance data were available, however, for some aircraft engine emissions in the afterburner mode, but most of these data were not usable.

C. REQUIREMENT TO DEVELOP TEST PROCEDURES

In order to verify that a detector will not respond to certain false alarm sources the detector should be subjected to certain tests that demonstrate this immunity.

The test procedures can be used in total or in part depending upon (1) the type of fire detector of interest, (2) the nature of the application, and (3) the types of possible nonfire radiation stimuli sources that the detector may be exposed to.

SECTION III

TECHNICAL APPROACH

A. GENERAL DESCRIPTION

The approach was to first identify the various types of UV and IR emitters that fire detectors could be exposed to in operational Air Force aircraft hangars, shelters, support areas, and maintenance facilities. Reviews were made of false alarm reports on file at the Naval Safety Center and the Air Force Inspection Safety Center. Additional study was made of the causes of these reported events and other events made known by detector suppliers and military personnel.

The detector industry was very helpful in identifying causes of some false alarm events involving their respective detectors.

Visits were made to Air Force bases where surveys were made of installed fire protection systems. Discussions were held with Fire Department, Civil Engineering, Operations, and Maintenance personnel regarding past false alarms and accidental activations of the fire suppressant systems. Discussions were also held on the nature and properties of various types of welding operations/ apparatus, aircraft engine emissions, non-destructive X-ray testing equipment, lights, personnel heaters, tools, aircraft ground equipments (AGE), vehicle exhausts/manifolds, and many other items that were either hot bodies or UV emitters. Past event data was obtained from the Navy and Air Force Safety Centers (Reference 4).

After candidate false alarm sources were identified, arrangements were made with Edwards Air Force Base to conduct additional detailed surveys and to make spectral emission measurements of JP-4 fires and major false alarm source candidates. These measurements included aircraft engine emissions, photographic lights, facility and area lights, aircraft lights, all welding processes, and all AGE equipment items (including their lamps and exhaust manifolds).

Following this field data acquisition effort, additional measurements were made in the laboratory of the UV and IR emissions/radiations from objects that were not easily available at Edwards AFB. This included certain lamps, heaters, aircraft lights, and items used as simulations of potential false alarm sources that were not accessible for measurement.

This aggregate of data was then analyzed and candidate false alarm sources selected, based upon their characteristics in relation to the properties of fire and the detection techniques.

The false alarm threat from those sources identified as candidates was further evaluated in terms of their possible distance from a detector in a "real-life" situation. For instance, a certain type of lamp located 10 feet from a detector may have a great enough irradiance to set off the detector, but at 30 feet the irradiance may be too low to cause a problem to the specific type of detector set at its specific threshold. The source may be identified however, as a possible false alarm source, because under certain conditions there is the possibility that the lamp could be closer to the detector or a different type of detector may have greater sensitivity to the source.

Eight different detectors (four types) were obtained from detector manufacturers and mounted on a mobile fixture with various data recording devices. A removable "chopper" wheel with two cut-outs was mounted directly in front of the fields-of-view of the detectors. A selection of possible false alarm lights and hot bodies were mounted on other mobile fixtures. Sources that could not be mounted or tested in the lab were simulated to some degree.

Methods of conducting the qualification tests were verified by testing the response of detectors to one or more of the false alarm sources in the FOV of the detectors. The procedures for these tests were then written and the tests were repeated to verify that they could be conducted with ease. No attempt was made to qualify one detector against another for response characteristics or false alarm performance. Only LED illuminations revealed detector responses. No manufacturer was permitted to participate or view any of the tests and no test results were made available to anyone. Where appropriate, detector manufacturers were verbally informed of their detector's response during development of the test procedures.

The analyzed data were then tabulated and compared with fire emission data. This revealed certain potential false alarm problems that should be addressed by a user agency when designing the fire protection system configuration and determining the layout of the facility and what operations should and should not take place therein.

The data and related information on the sources were then included in this document and in Appendix I. The qualification test procedures were included in Appendix II herein.

B. FIRE DETECTORS

Hydrocarbon fires, such as from aircraft fuels (e.g., JP-4, JP-8, AV-A, etc.), emit radiation in the wavelength range of about 180 nanometers to about 5 micrometers (see Figures 1, 2, and 3). This range includes the ultraviolet, visible and infrared regions of the electromagnetic spectrum.

Figure 1 (Reference 1) shows the UV emissions from JP-4 fuel burning at sea level. The figure is separated into three parts that are extensions from left to right. The plot on the left shows the spectral radiant intensity of 200 nm - 400 nm UV emission over the range of about zero to 8 x 10^{-9} watts/nm/sr. The middle plot is a continuation of the left plot where the ordinate extends from 9 x 10^{-9} watts/nm/sr to 8 x 10^{-8} watts/nm/sr over the wavelength range of about 240 nm through 280 nm. The plot at the right is a continuation of the middle plot and shows a continuing rise in energy emission from about 280 nm through the peak intensity level of 4 x 10^{-7} watts/nm/sr at 310 nm.

Figure 2 (Reference 2) shows the broad-band emissions in the visible and near-infrared regions for JP-4 burning at various atmospheric pressures. It is apparent that most of the near infrared energy is contained in the wavelength range of about 1.2 μm to about 2.0 μm.

Figure 3 (Reference 3) shows the predominant emission "spike" near 4.4 micrometers due to CO_2.

The regions in which fire detectors operate are determined primarily by the amount of energy emitted at certain wavelengths and the amount of background solar radiation that may be present at these same wavelengths. In the infrared, hydrocarbon fires emit strongly in the 4.1 μm - 4.6 μm band, while very little solar radiation in this region penetrates the atmosphere due to carbon dioxide absorption (see Figure 4). The narrow emission band located near 4.4 μm is usually chosen as the center of the infrared detection band because it is the predominant spectral emission from hydrocarbon fires.

In the UV, very little solar radiation in the wavelength band of about 180 nm - 220 nm penetrates the atmosphere due to water vapor absorption (Figure 4). In the range of about 240 nm to about 290 nm the atmosphere is relatively transparent, thus having little effect on UV transmission. Although the radiant intensity of UV emitted in this region from fires is very low, it is easily discernable over the low level background with rather simple detection methods.

UV detectors normally use a Geiger Mueller type of tube which responds to UV in the region 185 nm to about 260 nm or less. The principle of operation is as follows:

When a UV photon hits a metal plate such as a negatively charged cathode, made out of a material such as tungsten, an electron will leave its surface only when the wavelength of the incident UV is shorter than about 250 nm. This electron, in turn, strikes a gas molecule (usually hydrogen or helium) causing additional electrons from the gas molecule to be emitted. These

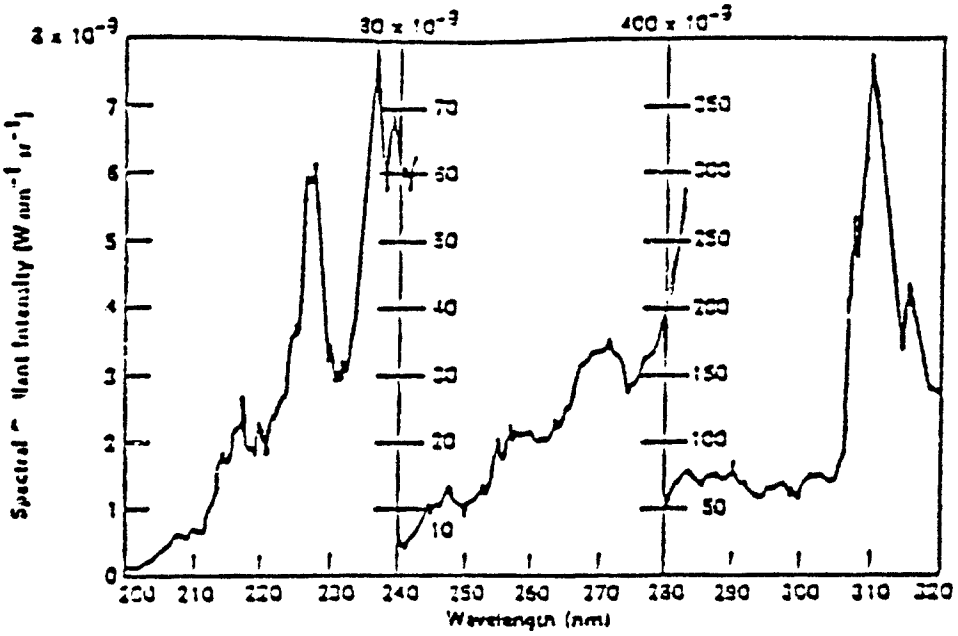


Figure 1. Spectral Radiant Intensity of JP-4 Burning at Sea Level (200-320 nm)

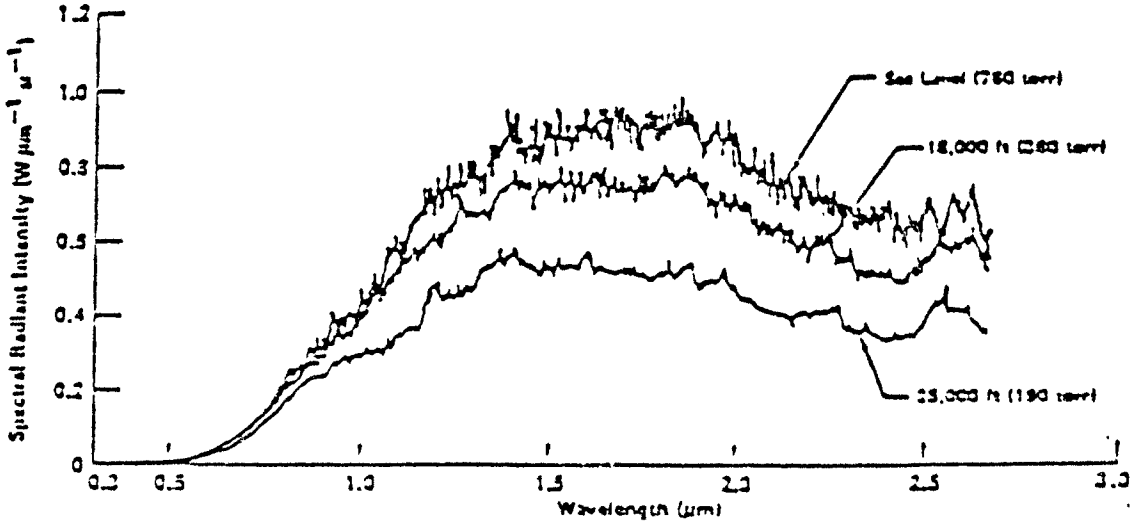


Figure 2. Visible and Near Infrared Emissions from JP-4 Burning at Various Altitudes

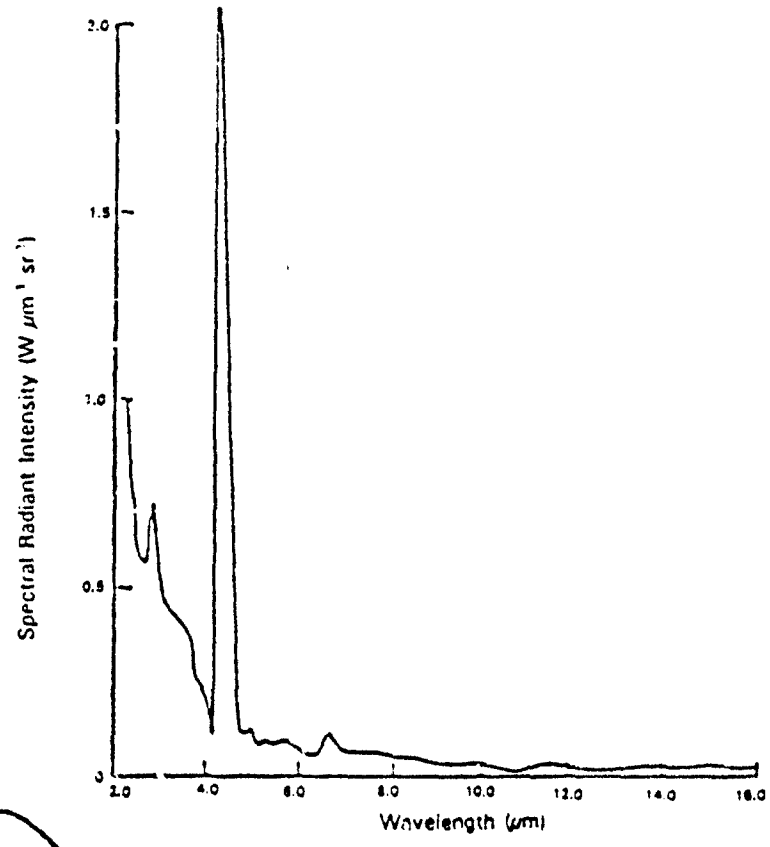


Figure 3. Far Infrared Emissions from JP-4 Burning at Sea Level

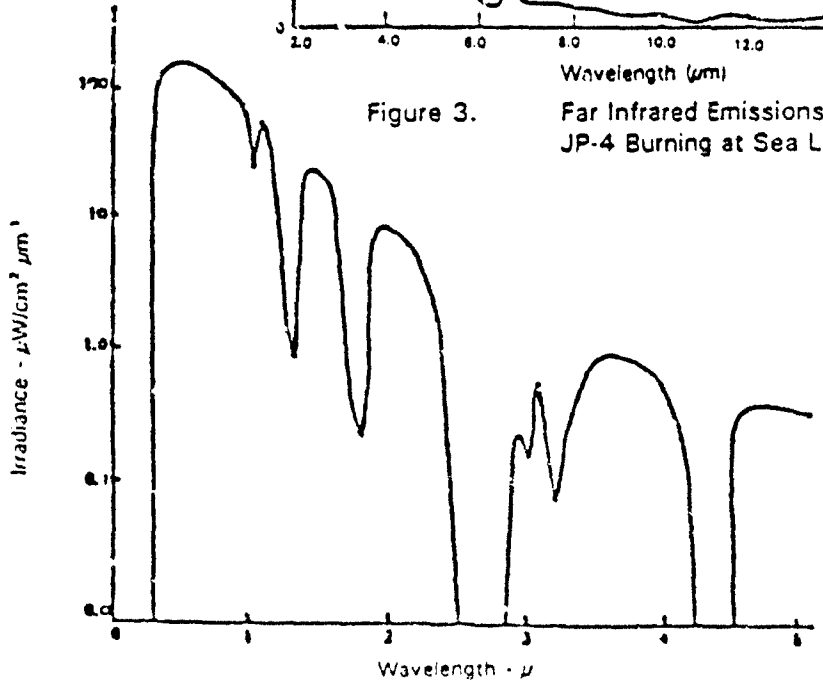


Figure 4. Spectral Irradiance vs. Wavelength for Solar Radiation

electrons also strike other molecules until an "avalanche" of electrons occurs which results in a current between the cathode and anode. The current flow can be stopped by removing the voltage applied between the cathode and anode, or reversing the charge on the cathode and anode. The current is allowed to flow for a very short time and then interrupted. The frequency with which this voltage (or switch) is turned on and off is directly proportional to the intensity of the UV radiation striking the detector.

The glass tube envelope is usually made of quartz, which is opaque to wavelengths shorter than 185 nm. Therefore, it is obvious that most UV detectors using this measurement technique operate between 185 nm and about 250 nm, although some, with different cathode materials and fill gases operate out to about 260 nm. A UV tube can then be constructed out of different types of glass and cathode materials to define the wavelength sensitivity band, and the gases used in the fill can be changed to affect the efficiency of the avalanche as well as the quenching of the avalanche.

It is apparent then that there are at least two portions of the electromagnetic spectrum in which optical fire detectors can operate effectively, namely, in the band 185 nm - 250 nm (centered near 220 nm), and 4.2 μm - 4.6 μm (centered near 4.37 μm). There are other areas in the UV and IR where emissions occur that are specific to the fire type.

There are several models of commercial fire detectors today. These include single band IR, single band UV, multiple band IR, multiple band UV, combined UV and IR bands, and a combination of UV, IR and visible. The IR detectors can either function as a flame detector or as a "heat" detector, while the UV detectors are flame-type detectors. Most detectors used by the Air Force for aircraft hangar/shelter applications, such as the applications of prime interest herein, are of the combined single band UV and single band IR-type.

The older types of flame detectors were single-band IR or single-band UV. Some are still installed in operational bases but most have been disconnected because of repeated false alarms. As will be shown herein, these single band type of detectors are very easy to fool with many types of nonfire sources of radiation stimuli.

Because of the problems with single band UV and IR detectors, detector manufacturers combined them into one multiple wavelength detector, which requires detection of both UV and IR radiation to determine the presence of a flame. This approach reduced the number of false alarms associated with single band detectors. However, as more sources of UV and IR were included in aircraft shelters and hangars and operations became more complex, false alarms continued to occur.

As another means to reduce false alarms, some suppliers added a feature to their UV/IR detectors that required the IR signal to vary at a frequency between 1 and 10 Hz, the flame "flicker" frequency. Other suppliers added other features such as "ratioing" between the UV and IR signals, or detection of emissions in the visible. These detectors today, although much improved in their false alarm immunity, still can be falsely triggered by the presence of certain types of nonfire sources within their FOVs and by moving objects that cause spatial and temporal changes of the radiation due to moving objects or other phenomena. New fire detection concepts are in development, such as machine vision, which may further reduce the possibility of false alarms as well as possibly increasing detection performance.

C. CANDIDATE FALSE ALARM SOURCES

As stated above, fire detectors are designed to sense particular characteristics of fires. These differ widely, however, depending on what fire characteristics are chosen to achieve fire detection specificity, and to discriminate a fire from all other possible "nonfire sources." There are nonfire sources which have some if not all of the fire characteristics incorporated in some detection methods.

The range of fire detection characteristics include:

(1) spectral: UV, visible and/or IR irradiance, or temperature
(2) temporal: strobing, flickering, chopping, random motion, rate-of-change
(3) spatial: growth or decay in size
(4) any other feature that enhances specificity and/or discrimination

The history of application of most of these in various Air Force fire protection applications, however, shows that no current commercial system has proven immune from all "false alarms." When investigated as to cause, the presence of a number of sources, and/or the condition of a source at a particular time, are regularly deduced as the cause.

This report considers those identified false alarm candidates as to their: (1) UV output, (2) visible output, (3) IR output, (4) temporal behavior, (5) spatial behavior, and (6) any other feature that a detector may wrongly sense as a fire feature.

Candidate false alarm sources are listed in Table 1 (Reference 4). These sources have been grouped into eleven major technical categories. A detailed investigation and delineation of the "fire-similar" characteristics of each item can be made: (1) by actual measurement in the field and in the laboratory of their radiation emission characteristics; and (2) by analysis of data supplied by

manufacturers. Verifications can also be made by exposing such sources to commercial fire detectors.

In Table 1, a primary source of ultraviolet radiation is from "lights," in particular the High Intensity Discharge (HID) lamps. The fluorescent lamps likewise emit a small percentage of ultraviolet light, and are used either alone or in combination with HID lamps and quartz tungsten halogen lamps. Many USAFE and NATO shelters employ fluorescent and quartz tungsten halogen lamps. The HID lamps, however, are the primary lighting sources for Air Force hangars. Figure 5 shows typical configurations of such lamps in hangars such as at Edwards AFB.

The other lamps indicated in Table 1 that are used extensively, and can be likely sources to cause false alarms, are incandescent lamps. These emit a high level of intensity of broadband IR radiation. One of these can be as small as a flashlight unintentionally in close proximity to or directed at an IR fire detector, to as large as a very high wattage tungsten halogen lamp a considerable distance away. But, the higher wattage incandescent lamps such as the quartz tungsten halogen lamps, also produce UV radiation. As will also be seen, the combination of UV and IR emissions from such lamps, even at rather large distances from the detector, are sufficient in intensities to cause some UV/IR detectors to false alarm, depending upon their sensitivity threshold and other detection parameters.

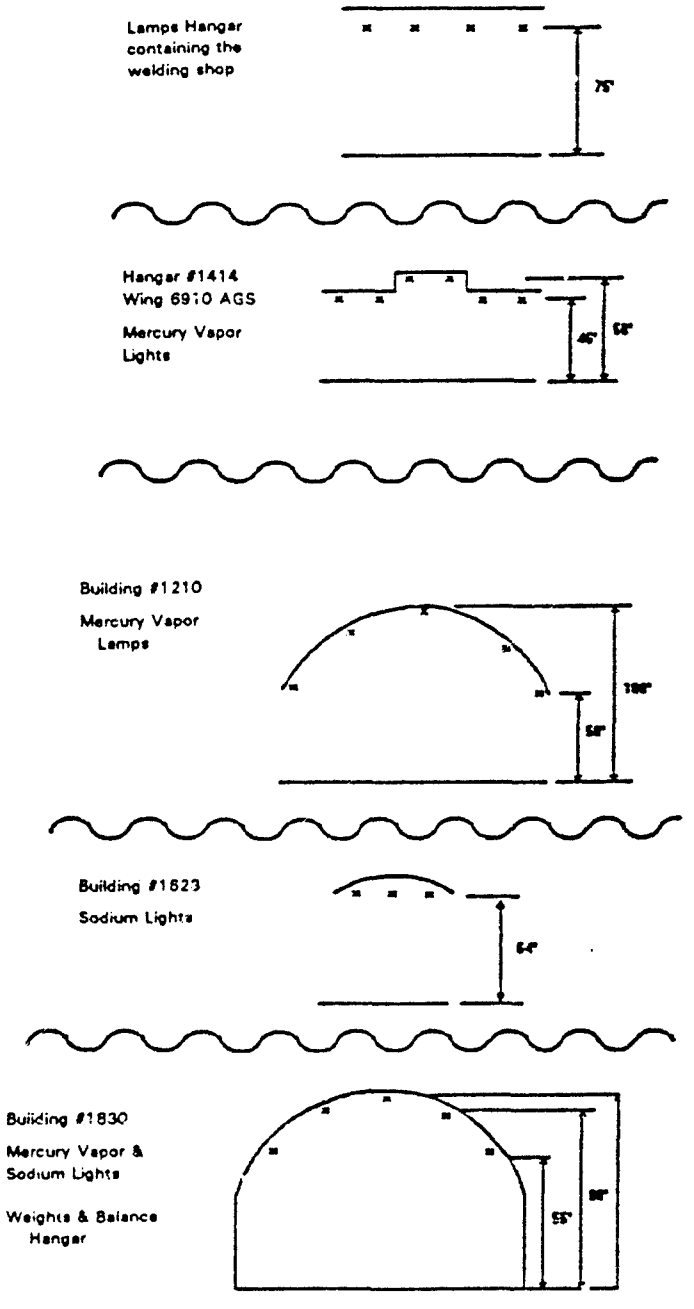


Figure 5. Typical Placement of High-Intensity Discharge Lamps in AF Hangars/Facilities

Table 1

Technical Categories of Possible False Alarm Sources

1. Lights

1.1 High Intensity Discharge (HID) Lamps

1.1.1	High Pressure Sodium	1000 W
1.1.2	Mercury Vapor	400, 1000 W
1.1.3	Metal Halide	400, 1000, 1500 W
1.1.4	Low Pressure Sodium	
1.1.5	Xenon	

1.2 Fluorescent Lamps (96 inch length)

1.2.1	Cool White
1.2.2	Deluxe Cool White
1.2.3	Warm White
1.2.4	Deluxe Warm White
1.2.5	White
1.2.6	Daylight
1.2.7	Black Light

1.3 Incandescent Lamps

1.3.1	Quartz Tungsten Halogen	300, 500, 1000, 1500 W
1.3.2	Sealed Beam - Aircraft:	
1.3.2.1	Landing	75, 100, 250, 450, 600, 1000 W
1.3.2.2	Navigation	100 W
1.3.2.3	Anticollision (Strobe)	35, 37.5, 60 W
1.3.2.4	Tail Fin	100 W
1.3.2.5	Taxiing	150, 250, 450 W
1.3.2.6	In-Air Refueling	50 W
1.3.3	Sealed Beam - Automotive:	
1.3.3.1	Headlamp	35, 45, 50, 65, 80, 100 W
1.3.3.2	Spotlamp	30, 37.5, 50, 100, 150 W
1.3.3.3	Signal	30 W
1.3.3.4	Light Bar	35, 60 W
1.3.3.5	Rotating Lights	35, 60 W
1.3.4	Flashlight	0.2, 0.4, 0.6, 0.7, 1.1, 1.2, 1.8, 3.1, 3.2 W
1.3.5	Flashlight with Red Lens	
1.3.6	Rough Service	100 W
1.3.7	Movie Projector	100, 250, 300, 500, 1000, 1500W
1.3.8	Blue Green Dome Light	

Table 1 (Continued)

1.3.9 Red Light
1.3.10 Vehicle Infrared Light

2. Reflected Light

Specifics discussed in text. High UV and IR reflectances exist.

3. Natural Phenomena

3.1 Sunlight: direct, scattered, reflected
3.2 Lightning

4. Electrical Discharge

4.1 Arcing

4.1.1 Power Transformers
4.1.2 Motors
4.1.3 Electrical Devices
4.1.4 Faulty Wiring

4.2 Flashlamps
4.3 Carbon Arcs

5. Nondestructive Investigative Devices (NDI)

5.1 Scattered X-rays, 160-300 kev
5.2 Scattered Secondary UV, Direct, Reflected

6. Electromagnetic Waves

6.1 Communication Devices
6.2 Aircraft Radar Jammers
6.3 IR Emission from Aircraft Jammers
6.4 Electric Power Switching
6.5 EMI from Electronic Equipment:

6.5.1 Subsystems
6.5.2 Communication Jammers
6.5.3 Decoys
6.5.4 Weapon Systems

7. Aircraft Engine Emissions

7.1 Engine Exhaust During Start-Ups
7.2 Engine Power Settings 20% through 80% (military)
7.3 Afterburner Operation
7.4 Black Powder Cartridge Start

Table 1 (Continued)

7.5 APU 60
7.6 Wet Start or Backfire in Exhaust

8. Personnel Items

8.1 Lighted Cigarette, Cigar, Pipe
8.2 Matches (paper and wood)
8.3 Butane Lighter

9. Tools/Operations

9.1 Welding Operations

9.1.1 TIG
9.1.2 Arc
9.1.3 MIG

9.2 Acetylene Welding and Cutting Operations

10. Hot Bodies, Blackbody Radiators

10.1 Vehicle Engines, Manifolds, Exhausts, Radiators, Mufflers
10.2 AGE Equipment Engines, Manifolds, Exhausts, Radiators, Mufflers

10.2.1 TTU 228/E Hydraulic Test Stand
10.2.2 MA3 Air Conditioner
10.2.3 AM 32A95 Gas Turbine Compressor
10.2.4 MHU 83CE Truck Lift
10.2.5 AM 32A60B Gas Turbine Generator
10.2.6 MC2A Diesel Rotary Air Compressor
10.2.7 H1 Gasoline Heater
10.2.8 AF/M32T-1 Aircraft Tester
10.2.9 MC2A Gasoline Air Compressor
10.2.10 MC1A Compressor
10.2.11 AM 32A-86 Generator Set

10.3 Thermal Heating Blankets
10.4 Aircraft Heaters/Blowers
10.5 Aircraft Brakes, Engine Nozzles, Pods
10.6 Radiator Heaters (1.0 and 1.5 Kw with Fan)
10.7 Radiator Kerosene Heater (70,000 BTU with Fan)
10.8 Hot Lamps
10.9 Hot Welding Materials
10.10
11. Security Personnel Weapons

11.1 M-16 Rifles
11.2 M-60 Machine Guns
11.3 M-79 Grenade Launchers

Table 1 (Continued)

11.4 38 Caliber Pistols
11.5 12-Gauge Shotguns

12. Fire/Explosive Events Associated with Aircraft and AGE Engine Wet Starts/Backfires

In general, however, lamps are not the only sources of IR radiation that can trigger false alarms. Practically everything that can become hot, whether due to its mode of operation or any other cause, can trigger an IR fire detector. Practically everything listed in Table 1 emits IR radiation, including the HID lamps.

As will become evident in this document, to the extent feasible, all the categories of Table 1 have been studied on site at Edwards AFB. This includes JP-4 fuel burns. Where this was not readily possible or convenient, studies were made in the laboratory, and/or based on data from manufacturers, or from qualified reports of other researchers.

The consolidation, correlation and screening of this extensive body of data demonstrate the degree of difficulty facing the fire detector designer to devise a means of ensuring against every false alarm source. It is a practical impossibility to achieve zero false alarms in the face of all the possible eventualities that result from using UV and/or IR characteristics of fuel fires. However, the practical possibility is that the number of false alarms can be reduced by design to a very small number. The end objective of this document is to aid the manufacturer to achieve that objective in using the technologies presently being applied. How this is achieved is a major challenge to every designer's creativity.

Therefore, this document will cover the information in the following order:

1) Edwards AFB in situ measurement of potential false alarm sources, results and conclusions;

2) manufacturers' data used to provide information not obtainable in 1) above; or to supplement it;

3) laboratory measurement of potential false alarm sources not feasible in situ at Edwards AFB;

4) research data in the reports of qualified researchers not obtained in (1) through (3) above.

The endeavor to develop as comprehensive a document as is currently possible for possible false alarm sources is thereby

achieved. It serves as the basis for defining the set of tests each fire detector may be required to pass in order to qualify it as an "immune" fire detector. It also serves as a reference guide to the facility designer/operator in what types of operations and facility support items (e.g. lights) are to be employed and where they should be placed. By these means it is expected that the number of false alarm incidents will be minimized regardless of the type of detector to be employed, and the goal of attaining zero false alarms will become a closer realization.

D. INSTRUMENTATION

Acquisition of the necessary complement of field-usable instruments was the first necessary effort. Achieving this as economically as possible was a prime consideration, provided proper and practical measurements could be made of the candidate sources in the UV and IR bands of interest.

The instruments chosen, and the reasons for their choice, are briefly summarized as follows:

1. Ultraviolet Instruments

a. Spectronics Spectroline DM-series digital radiometers for 5 bands (see Figure 6 [Reference 5]):

254 nm band: from 243 to 269 nm
300 nm band: from 272 to 326 nm
365 nm band: from 310 to 385 nm
405 nm band: from 396 to 412 nm
450 nm band: from 395 to 486 nm

b. Photomultiplier (Hammamatsu) with Oriel housing, power supply and extreme UV filter having a peak wavelength at 200 nm, a passband from 185.2 nm to 250 nm, and a transmittance of 28% at 200 nm (see Figure 7 [Reference 6]), and a Keithley picoammeter for signal readout;

c. UV fire detector adapted to function as a UV radiometer with analog output, and its power supply;

d. Deuterium lamp and power supply for calibration in the extreme UV region.

The Spectronics radiometers are absolutely calibrated sensors, and have been shown by the Air Force Materials Laboratory to meet the requirements of MIL-I-6868 E concerning measurement of UV in nondestructive testing. Each having a 1 cm^2 window, their FOV is 180° which needs to be properly considered in their use. The fire radiometers were mounted on one board, with a switch to step

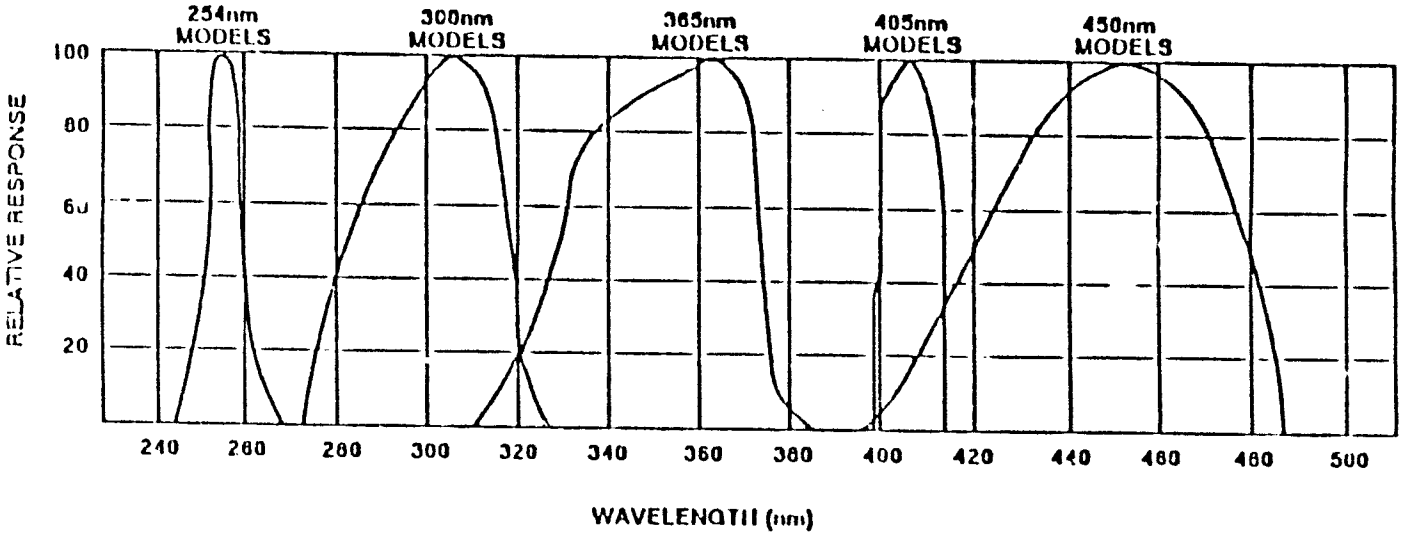


Figure 6. Spectral Sensitivities (Typical) of Spectroline Digital Radiometers

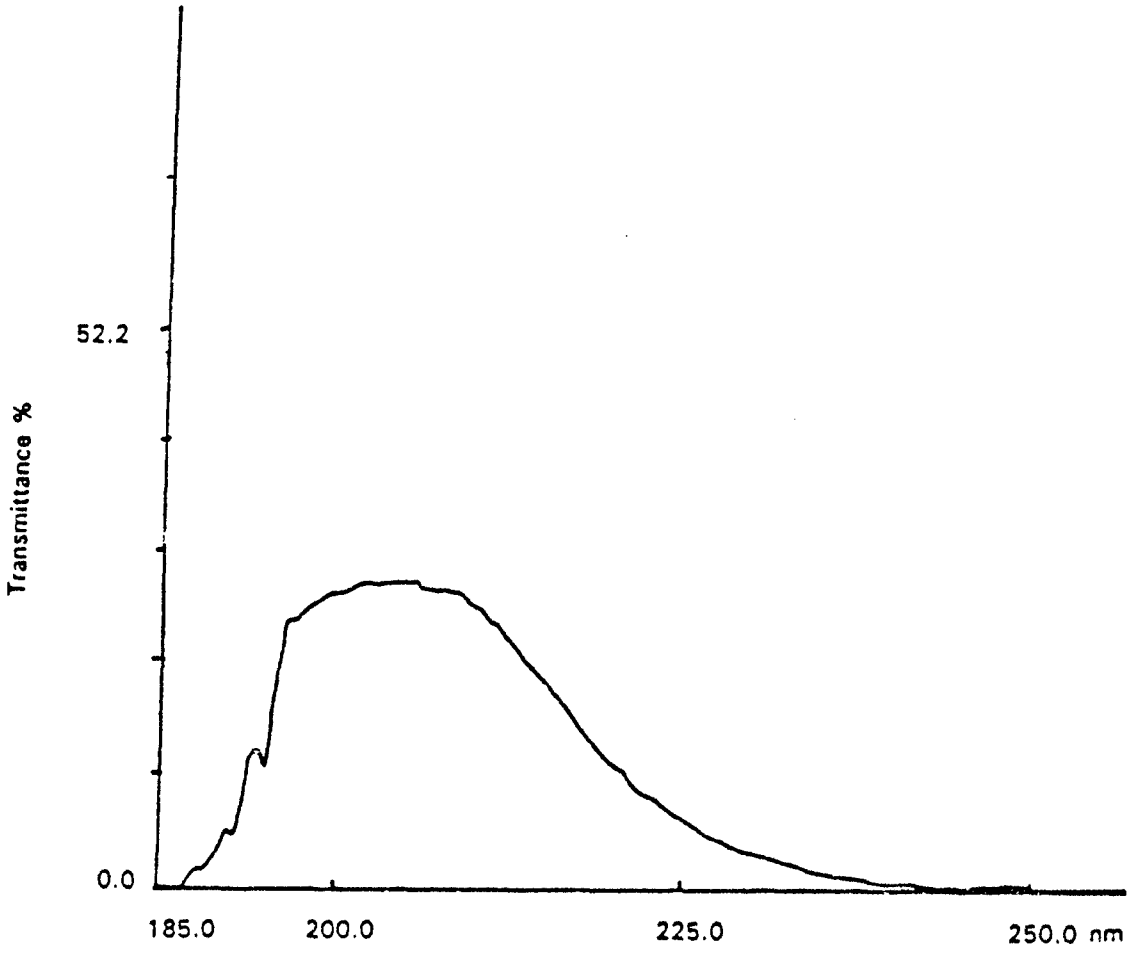


Figure 7. Transmittance of UV Filter

through each band successively during a measurement run; the digital readout meter gives the irradiances in microwatts per square centimeter.

The photomultiplier system for the most sensitive measurement of signals in the "extreme UV" ensured that even the smallest flux would be sensed by this system. Where the Keithley picoammeter, provided the noise was correspondingly low, would have been able to measure signals as small as 10^{-15} amperes (corresponding to around 10^{-15} $\mu W/cm^2$ irradiance), it was found that signals measured were typically in the high signal range of 10^{-3} to 10^{-6} amperes, corresponding to UV irradiances in the range of about 10^{-3} to 10^{-6} $\mu W/cm^2$. The welding signals, however, were very high, in the range of 10^{-1} to 10^{-4} amperes, corresponding to UV irradiances in the range of about 10^{-1} to 10^{-4} $\mu W/cm^2$. The irradiance values are discussed below.

The UV filter was checked carefully with a NIST referenced standard lamp and a scanning spectrometer for transmittance of any visible light to the photomultiplier. The results in Figure 8 show that, from 300 nm to 900 nm, any transmittance is lost in the random noise of the system, decades below the standard lamp signal. Effectively, it makes a very good sensing system for the extreme UV region. Moreover, it gave a measurable signal throughout every measurement made at Edwards AFB, proving an invaluable source of information in a spectral region where UV fire detectors commonly operate. No source measured at Edwards AFB was without some signal level in this region.

The UV fire detector that was adapted to function as a radiometer likewise indicated a signal in every measurement, corroborating the photomultiplier results. In the Photo Laboratory at Edwards AFB, where flash lamps were measured, the response time of this detector was too long to measure the flashes. Also, since it was not feasible to reset the sensitivity in the field, this sensor frequently recorded saturated signals. Hence, its data is tabulated in the data tables as a Y for "go", and an N for "no-go."

The deuterium lamp enables an absolute calibration of the photomultiplier system to be made, as well as serves as a known source for checking out any UV fire detector. It is expected that, with this overall excellent capability for this spectral region, new information would be obtained.

2. Infrared Instruments

   a. Raytek remote sensing noncontact thermometer with a 2° FOV and a built-in laser for fixing on a target spot, and sensing in the 8 to 14 μm band, internally processed to give a remote temperature reading for a chosen emissivity;

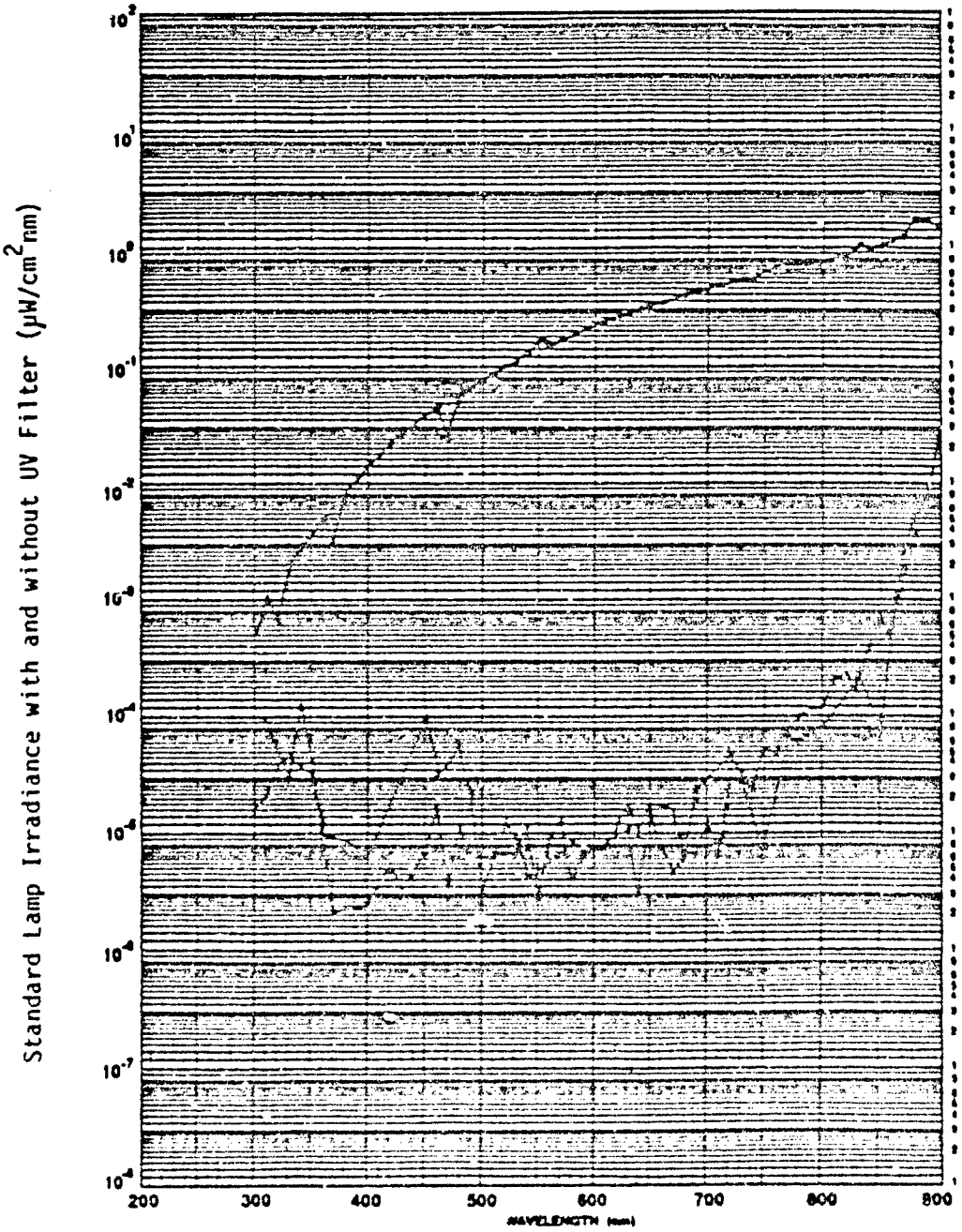


Figure 8. Comparison of UV Filter Transmittance of Standard Lamp Irradiance with No Filter Signal and Dark Current of Absolute Spectroradiometer System

b. Fluke contact thermometer, using thermocouples to enable, if feasible, determination of the true target temperature and target emissivity over the range of interest.

c. Lead Selenide photoconductive cell, sensing over a wide IR band from 1.5 to 6 μm;

d. Lead Selenide photoconductive cell, with a narrow band filter, sensing at 4.4 μm within a narrow IR band of 650 nm FWHM;

e. IR fire detector adapted to function as radiometer with analog output.

f. Blackbody radiation source for absolute calibration of the IR sensors.

The strategy used in making the IR field measurements with as simple and inexpensive a complement of IR instruments as possible is based on the physics of the black and gray body radiances of the targets measured. First, the true contact temperature of the target is determined by using a Fluke thermocouple, if feasible. The Raytek noncontact thermometer is then used to measure the emissivity, if feasible, by setting the Raytek emissivity to give the same temperature reading as the Fluke thermocouple reading. In this way, the in-situ emissivity of the target is determined.

With this data, the Stefan-Boltzman law is then applied, enabling computation of the total radiance of the target. The peak wavelength is then computed using Wien's displacement law.

Since the known spectral radiance of fuel fires establishes the wavelengths or bands of interest exploited in IR fire detector designs, the particularly strong spectral feature at 4.4 μm is chosen here for computation of the target radiance at that wavelength. By applying Planck's equation to the data, it is possible to determine the target radiance at 4.4 μm, or at any other wavelength or band.

In this way, even though the measurements were not made directly at the wavelengths and bands of interest, the justified assumption that the target source would exhibit the characteristic continuum of radiance of a black or gray body in turn justifies the values obtained at the different wavelengths and bands.

It is recognized that modifications to such spectral radiances can occur that are specific to the materials of the target. This, however, is or is not indicated by the other sensors used in the measurement procedure, as will be seen in the resulting

data discussed below. The wide band and narrow band IR lead selenide sensors serve this purpose, as does the IR fire detector. At the time of the AGE equipment measurements at Edwards AFB, however, the wide and narrow band and fire IR detectors were not available. Hence, their corroborative responses are not available for those measurements.

The wide and narrow band IR sensors differed in their responses. Since there was no provision to change sensitivity settings in the field, each responded to the particular single setting range chosen for it. As a consequence, the wide band IR sensor almost always was driven into saturation, whereas conversely the narrow band IR sensor rarely indicated a measurable signal. To counteract the saturation of the wide band sensor, a set of collimating tubes of different lengths were used to drastically reduce the FOV as well as ensure, if possible, that only the target area was filling the FOV. It was found that even this reduction did not keep the wide band sensor from saturating. Three collimating tubes, each with an internal diameter of 7/8 inches, were used in lengths of 3, 6 and 12 inches respectively. The 12 inch tube was used for most of the measurements. Some measurements were not saturated or zero, both the wide and narrow band detectors providing some useful data as given below.

The IR fire detector functioned similarly as the UV fire detector described above. Having the same response time limitation as the UV fire detector, it did not respond at all to the photclaboratory flash or steady burning irradiances, but responded to all JP-4 fuel burns, both daytime and nighttime, except one; and to only two welding radiances.

Similar to the UV fire detector, a "go" response is indicated as a Y, and a "no go" response as an N.

The blackbody calibration source is used to calibrate all the IR sensors. With a known emissivity of 0.97 and a temperature as indicated by its readout sensor, counterchecked by the Raytek IR radiation thermometer, each total radiance is computed on the basis of the data measured. The calibration curves of target radiance versus sensor signal are determined accordingly.

3. Recording Instruments

   a. Gould 8-channel Strip Chart Recorder to which 5 sensors were connected:

      1. U.V. photomultiplier
      2. Wide band IR sensor
      3. Narrow band IR sensor
      4. UV fire detector
      5. IR fire detector

b. Toshiba computer to which the Raytek instrument was connected.

c. Spectronics 5-radiometer digital readout, which was manually recorded.

All the sensors were mounted on tripods for optimum placement for measuring target radiances. Supporting instruments were placed on a mobile cart or tables. The same set-ups and procedures were used for both indoor and outdoor measurements.

F. EDWARDS AFB FIELD MEASUREMENTS

The particular sites and equipment at Edwards AFB at which UV and IR measurements were made are the following.

(1) Fuel Burn Site: Daytime and nighttime burns of JP-4 fuel in 1 x 1 ft., 2 x 2 ft. and 4 x 4 ft. pans were measured at 25, 50, 75 and 100 ft. distances.

(2) Welding Shop Site: TIG welding of aluminum 6061, magnesium, titanium, stainless steel 410 and carbon steel with their appropriate rods; Arc welding of steel plate, carbon steel, stainless steel, nickel and aluminum with their appropriate rods; MIG welding of aluminum 4043 and mild steel with ER 70 S-6 wire; and finally oxyacetylene cutting and welding of mild steel;

(3) Photo Laboratory Site: Five flashlamps measured were: Norman 200B, Metz 60 CT-4, Vivitar 285 HB strobe, Norman 2000B and Norman P500; the Colortran 1000 quartz halogen flood light, EKI International movie projector, Kodak Ektigraf 3 ATS slide projector and 3M overhead projector also were measured;

(4) AGE Equipment Site: The NF-2 portable floodlight (2 lamps) and the TP-54A-DC floodlight set (4 lamps) Lightall units were measured for UV and IR outputs; and all of the following are listed in their order of descending IR output:

1. TTU 228/E hydraulic test stand
2. MA3 air-conditioner, trailer mounted
3. MA3D air-conditioner, trailer mounted
4. AM32A95 compressor, gas turbine
5. AM32A95 compressor, gas turbine
6. MHU83CE truck lift
7. AM32A60B generator, gas turbine
8. MC2A rotary air compressor, diesel
9. H-1 heater, engine and shelter, gasoline
10. AF/M32T-1 aircraft tester, pressurized cabin leakage

11. MC2A air compressor, gasoline engine
12. MC1A compressor
13. AM32A-86 generator set

After completion of the above measurements, the extensive bank of data was reduced, organized and converted to the same irradiance units of microwatts per square centimeter, commonly in use, to enable a direct comparison of all sources relative to each other. The results are tabulated in Table 2 in the next section.

It is to be noted that the daytime data for the JP-4 fuel burns are separately tabulated in Table 3. The reasons for this separation will become evident below.

The results obtained at the different sites are discussed in Section IV, followed by the conclusions and recommendations to which their interpretations and interrelationships lead.

SECTION IV

FIELD MEASUREMENTS RESULTS

A. THE JP-4 PAN FIRE BURNS, NIGHTTIME AND DAYTIME

The nighttime data in Table 2 provide the best irradiance values from JP-4 fuel burns that could be obtained without interference from background irradiances. In the daytime measurements, however, the opposite is true.

Comparing the values for corresponding pan fire sizes and distances in both Tables 2 and 3, it can be seen that the daytime values are much higher than the nighttime values. The reason is that the daytime values are dominated by the daytime background, whereas the nighttime values are without such a background. It is interesting to note that the fire reduces the daytime background by a small amount due to the attenuation caused by the flame and its smoke. With the small differences in the signal observed, estimated values of the transmittance T and the specific optical density δ per foot are calculated and included in Table 3.

To help understand Tables 2 and 3, a brief example is as follows.

In Table 2, taking the 1- x 1-foot JP-4 pan fire at the distance of 25 foot, the UV photomultiplier system recorded a signal current which corresponded to an irradiance of 6.1×10^{-4} $\mu W/cm^2$. The Spectronics 254 nm, 300 nm, 365 nm, and 450 nm sensors indicated no measurable irradiance, whereas the 405 nm sensor indicated an irradiance of 10 $\mu W/cm^2$. In the infrared, the Raytek thermometer indicated a temperature of 301°C with the emissivity at 0.99. Using the Raytek® values for temperature and emissivity, the irradiance from a hot source at these conditions was calculated from Planck's equation to provide an irradiance of 1.20×10^2 W/cm^2 at 4.3 μm. In addition, the wide band IR sensor did give an on-scale value, whereas the narrow band sensor gave no reading. Both the UV and IR fire detectors did respond to the fire, hence being recorded as a "Y" in both cases.

When the same case is reviewed in Table 3 for daytime conditions, this table is an example of how real time raw data was recorded at the time of the measurement, and reduced and converted thereafter to parameters of interest. Under an overall case heading of 1 foot x 1 foot Pan, Distance = 25 ft., there are typically five lines below in this table for data. The first line gives "Signal + Background" values during the fire. The second line gives the "Background" value measured alone with no fire burning. The third line is the "Signal" obtained by subtracting line two from line one. Whatever the units of the first three lines, the

Table 2

Measurement Data of JP-4 Fuel Burns and Possible False Alarm Sources at Edwards Air Force Base

ULTRAVIOLET					VISIBLE		INFRARED					FIRE DETECTORS	
DIS-TANCE FT.	UV PMT $\mu W/cm^2$	254 nm $\mu W/cm^2$	300 nm $\mu W/cm^2$	365 nm $\mu W/cm^2$	405 nm $\mu W/cm^2$	450 nm $\mu W/cm^2$	TEMP. °K	EMIS-SIVITY	IRRAD. 4.37μm $\mu W/cm^2$ μm	WBIR $\mu W/cm^2$ μm	NBIR $\mu W/cm^2$ μm	IR FIRE DET.	UV FIRE DET.
JP-4 FUEL PAN FIRES - NIGHTTIME													
I. 1 x 1 FT PANS													
25	6.1E-4	0	0	0	10	0	574	0.99	7.6E4	?	0	Y	Y
50	1.3E-4	0	0	0	0	0	NF			?	0	Y	Y
100	4.4E-5	0	0	0	0	0	NF			?	0	Y	Y
II. 2 x 2 FT PANS													
50	5.5E-4	0	0	0	0	0	NF			SAT	?	Y	Y
100	1.4E-4	0	0	0	0	0	NF			SAT	?	Y	Y
III. 4 x 4 FT PANS													
100	3.9E-4	0	0	0	-10	0	NF			SAT	?	Y	Y

Note: (1) Empty Data Blocks: Either Instrument was not acquired at the time, or became non-functional (NF) in the field.
(2) The wide and narrow band IR sensors (WBIR and NBIR) either saturated or gave no signal, or when a signal was on scale, were not reducible because of questionable calibration.
(3) The fire detectors used either indicated a signal(Y) or did not (N) for each measurement.

Table 2 (Continued)

DIS-TANCE FT.	UV PMT $\mu W/cm^2$	254 nm $\mu W/cm^2$	300 nm $\mu W/cm^2$	365 nm $\mu W/cm^2$	405 nm $\mu W/cm^2$	450 nm $\mu W/cm^2$	TEMP. °K	EMIS-SIVITY	IRRAD. 4.37μm $\mu W/cm^2$ μm	WBIR $\mu W/cm^2$ μm	NBIR $\mu W/cm^2$ μm	IR FIRE DET.	UV FIRE DET.
WELDING IRRADIANCES													
TIG WELDS													
I. ALUMINUM 6061, 4043 ROD													
4.5	5.51E-2	10	20	10	50-60	10	932	0.3	7.07E5	SENSOR ON "CALIBRATE"		N	Y
II. MAGNESIUM, AZ 318 ROD													
4.5	5.28E-2	10	20	10	30	0	923	0.2	6.82E5	SENSOR ON "CALIBRATE"		N	Y
III. TITANIUM, TITANIUM FILLER ROD													
4.5	4.73E-2	0	0	0	0	0	2200	0.6	6.77E6	SENSOR ON "CALIBRATE"		N	Y
IV. STAINLESS STEEL 410, 410 ROD													
4.5	4.84E-2	0	0	0	0	0	1789	0.15	4.43E6	?	?	N	Y
V. CARBON STEEL, CARBON STEEL ROD													
4.5	4.62E-2	0	0	0	0	0	1644	0.15	3.66E6	?	?	N	Y
ARC WELDS													
I. STEEL PLATE, 6013 ROD													
7	6.06E-2	20	50	40	20	20	1672	0.15	3.81E6	SAT	?	N	Y
II. CARBON STEEL, 6013 ROD													
7	5.28E-2	10-20	10-20	30-40	20	20	1644	0.15	3.66E6	SAT	?	Y	Y

NOTE: The data in the 3 columns, TEMP., EMISSIVITY, and IRRADIANCE at 4.37μm, are not measured, but are based on the known melting points of each material. The emmisivities are literature values for molten metals.

Table 2 (Continued)

DISTANCE FT.	UV PHT $\mu W/cm^2$	254 nm $\mu W/cm^2$	300 nm $\mu W/cm^2$	365 nm $\mu W/cm^2$	405 nm $\mu W/cm^2$	450 nm $\mu W/cm^2$	TEMP. °K	EMISSIVITY	IRRAD. 4.37μm $\mu W/cm^2$ μm	WBIR $\mu W/cm^2$ μm	NBIR $\mu W/cm^2$ μm	IR FIRE DET.	UV FIRE DET.
ARC WELDS (cont.)													
III. STAINLESS STEEL, 312-16 STAINLESS STEEL ROD													
7	5.51E-2	10	10-30	10-30	10-30	10	1789	0.15	4.43E6	SAT	0	N	Y
IV. NICKEL, NICKEL 141 ROD													
7	5.51E-2	10	30	30-40	10	10	1728	0.45	4.10E6	SAT	0	N	Y
V. ALUMINUM, EUTECTIC SUPER 2109 ROD													
7	8.81E-1	10-20	50-60	10	10	10-20	1422	0.2	2.57E6	SAT	0	N	Y
MIG WELDS													
I. ALUMINUM 4043, ER 70-6 WIRE													
7	6.06E-2	30-40	130	10-20	10-20	10	932	0.3	7.07E5	SAT	0	N	Y
II. MILD STEEL, ER 70S-6 WIRE													
7	6.06E-1	10-30	60-90	50-60	10-20	30-40	1772	0.15	4.34E6	SAT	0	N	Y
OXYACETYLENE CUT AND WELD													
I. CUTTING: MILD STEEL													
7	3.41E-3	0	0	0	0	0	1772	0.15	4.34E6	SAT	?	Y	Y
II. WELDING: MILD STEEL, MILD STEEL ROD													
7	2.48E-3	0	0	0	0	0	1772	0.15	4.34E6	?	0	N	Y

Table 2 (Continued)

DISTANCE FT.	UV PHT $\mu W/cm^2$	254 nm $\mu W/cm^2$	300 nm $\mu W/cm^2$	365 nm $\mu W/cm^2$	405 nm $\mu W/cm^2$	450 nm $\mu W/cm^2$	TEMP. °K	EMISSIVITY	IRRAD. 4.37μm $\mu W/cm^2$ μm	WBIR $\mu W/cm^2$ μm	NBIR $\mu W/cm^2$ μm	IR FIRE DET.	UV FIRE DET.
PHOTOLAB EQUIPMENT IRRADIANCES													
I. NORMAN 200B, LH2, NO WINDOW FLASHLAMP, 200 Wsec													
4.5	3.4E-3	60	10	60	110	110				SAT	0	N	N
II. METZ 60 CT-4, WITH WINDOW FLASHLAMP, 160W, VAR. PWR., VAR Wsec, AUTO RANGING													
4.5	4.9E-3	120	10	40	470	440				SAT	0	N	N
III. VIVITAR 285 HB STROBE, 125 Wsec, CONCENTRATED BEAM, F.P.													
4.5	2.1E-3	20	0	0	80	100				SAT	0	N	N
IV. NORMAN 2000 B STROBE, 2000 Wsec, 250 Wsec STANDBY													
4.5	2.8E-2	440	190	640	1270	1740				SAT	0	N	Y
						400 Wsec							
4.5	1.1E-2	40	30	80	290	300				SAT	0	N	Y
V. NORMAN P500, 500 Wsec, 125 Wsec													
4.5	2.3E-3	0	0	10	30	10				SAT	0	N	N
VI. COLORTRAN 1000, QUARTZ HALOGEN FLOOD, 1000 W, 250V													
4.5	4.4E-2	70	10	20	450	60				SAT	0	N	Y
VII. EKI INTERNATIONAL MOTION PICTURE PROJECTOR, 250W													
4.5	8.8E-4	20	0	0	110	140				0	0	N	N

Table 2 (Continued)

DIS-TANCE FT.	200 nm µW/cm²	254 nm µW/cm²	300 nm µW/cm²	365 nm µW/cm²	405 nm µW/cm²	450 nm µW/cm²	TEMP. °K	EMIS-SIVITY	IRRAD. 4.8 µm µW/cm² µm	WBIR µW/cm² µm	NBIR µW/cm² µm	IR FIRE DET.	UV FIRE DET.

PHOTOLAB EQUIPMENT IRRADIANCES (cont.)

VIII. KODAK EKTIGRAF 3, ATS PROJECTOR, 250W, 50V

4.5	1.7E-3	0	0	0	10	40				0	0	N	N

IX. 3M OVERHEAD PROJECTOR

4.5	1.9E-3	0	0	0	20	10				?	0	N	N

DIS-TANCE FT.	200 nm µW/cm²	254 nm µW/cm²	300 nm µW/cm²	365 nm µW/cm²	405 nm µW/cm²	450 nm µW/cm²	EMIS-SIVITY	TEMP. °K	PEAK λ µm	TOTAL IRRAD. µW/cm²	IRRADIANCES µW/cm²µm		
											3.0 µm	3.5 µm	4.37 µm

AGE EQUIPMENT IRRADIANCES

LIGHTALL UNITS

I. NF-2 PORTABLE FLOODLIGHT -(1) LENS ON; (2) LENS OFF: 2 LAMPS

	(1)	150	15	100	1410	1635	(1 LAMP)						
	(2)	300	150	2270	2410	2690	(1 LAMP)						
		POWER GENERATOR											
		NA	NA	NA	NA	NA	0.74	437	6.63	1.19E5	2.64E3	5.85E3	1.26E4

Table 2 (Continued)

DIS-TANCE FT.	200 nm µW/cm²	254 nm µW/cm²	300 nm µW/cm²	365 nm µW/cm²	405 nm µW/cm²	450 nm µW/cm²	EMIS-SIVITY	TEMP. °K	PEAK λ µm	TOTAL IRRAD. µW/cm²	IRRADIANCES µW/cm²µm		
											3.0 µm	3.5 µm	4.37 µm
LIGHTALL UNITS (cont.)													
II. TP-54HA-DC FLOODLIGHT SET - (1) LENS ON; (2) LENS OFF: 2 LAMPS													
.25	(1)	785	225	4205	5400	5090	(1 LAMP)						
.17	(2)	1035	645	8715	5620	2970	(1 LAMP)						
			DIESEL GENERATOR										
							1.00	414	7.0[illegible]	1.21E-5	1.43E3	3.47E3	8.26E3
OTHER UNITS													
III. TTU 228/E HYDRAULIC TEST STAND													
							0.32	944	3.07	1.43E6	9.63E5	9.27E5	7.40E5
IV. MA3 AIR CONDITIONER, TRAILER MOUNTED													
							0.39	841	3.44	1.09E6	5.15E5	5.41E5	4.78E5
V. MA3D AIR CONDITIONER, TRAILER MOUNTED													
							0.46	756	3.83	8.31E5	2.71E5	3.11E5	3.05E5
VI. AM 32 A95 COMPRESSOR, GAS TURBINE													
							0.95	617	4.70	7.37E5	6.48E4	9.11E4	1.14E5
VII. AM 32 A95 COMPRESSOR, GAS TURBINE													
							1.00	601	4.82	6.94E5	5.27E4	7.63E4	9.85E4

Table 2 (Continued)

DISTANCE FT.	200 nm µW/cm²	254 nm µW/cm²	300 nm µW/cm²	365 nm µW/cm²	405 nm µW/cm²	450 nm µW/cm²	EMISSIVITY	TEMP. °K	PEAK λ µm	TOTAL IRRAD. µW/cm²	IRRADIANCES µW/cm²µm		
											3.0 µm	3.5 µm	4.37 µm
OTHER UNITS (cont.)													
VIII. TYPE MHU 83 CE TRUCK LIFT, AERIAL STORES													
							1.00	472	6.14	2.35E5	5.95E3	1.18E4	2.20E4
IX. AM 32 A 60 B GENERATOR, GAS TURBINE													
							0.95	470	6.17	2.19E5	5.70E3	1.13E4	2.13E4
X. MC 2A ROTARY AIR COMPRESSOR, DIESEL													
							0.42	567	5.11	2.27E5	3.27E4	5.06E4	7.08E4
XI. TYPE H-1 HEATER, ENGINE AND SHELTER, GASOLINE													
							0.95	457	6.34	1.91E5	4.26E3	8.83E3	1.75E4
XII. AF/M 32 T-1 AIRCRAFT TESTER, PRESSURIZED CABIN LEAKAGE													
							1.00	434	6.68	1.55E5	2.44E3	5.48E3	1.19E4
XIII. MC2A AIR COMPRESSOR, GASOLINE ENGINE													
							0.12	729	3.98	1.27E5	2.14E5	2.54E5	2.59E5
XIV. MC1A COMPRESSOR													
							0.29	580	5.00	1.73E5	3.94E4	5.95E4	8.87E4
XV. AM32A-86 GENERATOR SET													
							0.23	437	6.63	1.37E5	2.64E3	5.85E3	1.26E4

Table 3

Measurement Data of Daytime JP-4 Fuel Burns At Edwards Air Force Base

	UV PMT	254 nm	300 nm	365 nm	405 nm	450 nm	WBIR	NBIR	IR FIRE DET.	UV FIRE DET.
	$\mu W/cm^2$	$\mu W/cm^2$	$\mu W/cm^2$	$\mu W/cm^2$	$\mu W/cm^2$	$\mu W/cm^2$				

I. 1 x 1 FT. PAN, DISTANCE = 15 FT, 2:10 P.M.

S+B*	4.5 E-2	50	40	220	270	320	SAT	?	Y	Y
B	4.5 E-2	50	50	260	280	390	?	0	N	N
S	0	0	-10	-40	-10	-70	SAT	?	Y	Y
**	0	0	T 0.80	T 0.85	T 0.96	T 0.82				
***	0	0	δ 3.1 E-5	δ 3.2 E-4	δ 7.0 E-5	δ 3.8 E-4				

II. 1 x 1 FT. PAN, DISTANCE = 25 FT., 2:20 P.M.

S+B*	4.6 E-2	50-40	40	210	240	330	SAT	0	Y	Y
B	4.5 E-2	40	40	220	240	340	?	0	N	N
S	0.1 E-2	0-10	0	-10	0	-10	SAT	0	Y	Y
**	1.0E-3	0-10	0	T 0.75	0	T 0.97				
***	7.3E-1	0-7.3E3	0	δ 2.0 E-4	0	δ 2.1 E-5				

* S+B: Signal + Background
B: Background alone
S: Signal alone
T: Transmittance of Smoke Produced by Burn
δ: Specific Optical Density per Foot of Smoke
** Irradiance in $\mu W/cm^2$, or Transmittance, T
*** Irradiance in $\mu W/cm^2$ at 1 Foot Distance, or δ

Table 3 (Continued)

	UV PMT	254 nm	300 nm	365 nm	405 nm	450 nm	WBIR	NBIR	IR FIRE DET.	UV FIRE DET.
	$\mu w/cm^2$	$\mu W/cm^2$	$\mu W/cm^2$	$\mu W/cm^2$	$\mu W/cm^2$	$\mu W/cm^2$				

III. 1 x 1 FT. PAN, DISTANCE = 50 FT., 2:35 P.M.

S+B*	4.6 E-2	40	40	200	220	320	?	0	Y	Y
B	4.5 E-2	40-50	40	210	230	330	?	0	N	N
S	1.7 E-3	-10-0	0	-10	-10	-10	?	0	Y	Y
**	1.7E-3	T 0.80	0	T 0.95	T 0.96	T 0.97				
***	5.7E0	δ 3.9 E-5	0	δ 8.5 E-6	δ 7.7 E-6	δ 5.3 E-6				

IV. 1 X 1 FT. PAN, DISTANCE = 75 FT., 2:47 P.M.

S+B*	4.5 E-2	40	30	190	210	300	?	0	Y	Y
B	4.4 E-2	40	30-40	200	220	320	?	0	N	N
S	1.1 E-3	0	-10-0	-10	-10	-20	?	0	Y	Y
**	1.1 E-3	0	T 0.75	T 0.95	T 0.95	T 0.94				
***	9.7 E0	0	δ 2.2 E-5	δ 4.0 E-6	δ 3.6 E-6	δ 5.0 E-6				

* S+B: Signal + Background
B: Background alone
S: Signal alone
T: Transmittance of Smoke Produced by Burn
δ: Specific Optical Density per Foot of Smoke
** Irradiance in $\mu W/cm^2$, or Transmittance, T
*** Irradiance in $\mu W/cm^2$ at 1 Foot Distance, or δ

Table 3 (Continued)

	UV PMT	254 nm	300 nm	365 nm	405 nm	450 nm	WBIR	NBIR	IR FIRE DET.	UV FIRE DET.
	$\mu w/cm^2$	$\mu W/cm^2$	$\mu W/cm^2$	$\mu W/cm^2$	$\mu W/cm^2$	$\mu W/cm^2$				

V. 1 X 1 FT. PAN, DISTANCE = 100 FT., 3:05 P.M.

S+B*	4.4 E-2	40	30	180	190	290	?	0	N	Y
B	4.5 E-2	40	30	190	200	300	?	0	N	N
S	-5.5 E-4	0	0	-10	-10	-10	?	0	N	Y
**	T 0.99	0	0	T 0.95	T 0.95	T 0.97				
***	δ 5.4 E-5	0	0	δ 2.3 E-5	δ 2.2 E-6	δ 1.5 E-6				

VI. 2 X 2 FT. PAN, DISTANCE = 25 FT., 3:40 P.M.

S+B*	3.7 E-2	30	20	100	140	190-210	MIRROR SAT	MIRROR ?	Y	Y
B	4.1 E-2	30	20	130	150	230	?	0	N	N
S	-3.3 E-3	0	0	-30	-10	-(20 - 40)	SAT	?	Y	Y
**	T 0.92	0	0	T 0.77	T 0.93	T 0.83				
***	δ 1.5 E-3	0	0	δ 1.8 E-4	δ 4.8 E-5	δ 1.3 E-4				

* S+B: Signal + Background
B: Background alone
S: Signal alone
T: Transmittance of Smoke Produced by Burn
δ: Specific Optical Density per Foot of Smoke
** Irradiance in $\mu W/cm^2$, or Transmittance, T
*** Irradiance in $\mu W/cm^2$ at 1 Foot Distance, or δ

Table 3 (Continued)

	UV PMT	254 nm	300 nm	365 nm	405 nm	450 nm	WBIR	NBIR	IR FIRE DET.	UV FIRE DET.
	$\mu W/cm^2$	$\mu W/cm^2$	$\mu W/cm^2$	$\mu W/cm^2$	$\mu W/cm^2$	$\mu W/cm^2$				

VII. 2 X 2 FT. PAN, DISTANCE = 50 FT., 3:37 P.M.

S+B*	4.1 E-2	30	20	120	160-170	230	?	0	Y	Y
B	4.4 E-2	30	20	150	170	250	?	0	N	N
S	-3.3 E-3	0	0	-30	-10-0	-20	?	0	Y	Y
**	T 0.93	0	0	T 0.80	T 0.94	T 0.92				
***	δ 6.3 E-4	0	0	δ 3.9 E-5	δ 1.1 E-5	δ 1.4 E-5				

VIII. 2 X 2 FT. PAN, DISTANCE = 75 FT., 3:17 P.M.

S+B*	4.3 E-2	30-40	20-30	140-150	170	250	SAT	0	Y	Y
B	4.4 E-2	30-40	30	170	190	280	?	0	N	N
S	-0.3 E-3	0	-10-0	-(20-30)	-20	-30	SAT	0	Y	Y
**	T 0.98	0	T 0.67	T 0.82	T 0.95	T 0.89				
***	δ 1.5 E-4	0	δ 3.1 E-5	δ 1.5 E-5	δ 8.6 E-6	δ 8.7 E-6				

* S+B: Signal + Background
B: Background alone
S: Signal alone
T: Transmittance of Smoke Produced by Burn
δ: Specific Optical Density per Foot of Smoke
** Irradiance in $\mu W/cm^2$, or Transmittance, T
*** Irradiance in $\mu W/cm^2$ at 1 Foot Distance, or δ

Table 3 (Continued)

	UV PMT	254 nm	300 nm	365 nm	405 nm	450 nm	WBIR	NBIR	IR FIRE DET.	UV FIRE DET.
	$\mu W/cm^2$	$\mu W/cm^2$	$\mu W/cm^2$	$\mu W/cm^2$	$\mu W/cm^2$	$\mu W/cm^2$				

IX. 2 X 2 FT. PAN, DISTANCE = 100 FT., 3:10 P.M.

S+B*	4.3 E-2	40	30	170	190	280	SAT	0	Y	Y
B	4.5 E-2	40	30	170	190	280	?	0	N	N
S	-0.2 E-3	0	0	0	0	0	SAT	0	Y	Y
**	T 0.96	0	0	0	0	0				
***	δ 1.6 E-4	0	0	0	0	0				

X. 4 X 4 FT. PANS, DISTANCE = 100 FT.

S+B*	3.6 E-2	20	10	90-80	130-140	170-180	SAT	0	Y	Y
B	4.0 F-2	20	10	100	120	200	?	0	N	N
S	-3.3 E-3	0	0	(-10-20)	10-20	-(10-30)	SAT	0	Y	Y
**	T 0.92	0	0	T 0.80	20	T 0.85				
***	δ 3.8 E-4	0	0	δ 9.7 E-6	200,000	δ 7.1 E-6				

* S+B: Signal + Background
B: Background alone
S: Signal alone
T: Transmittance of Smoke Produced by Burn
δ: Specific Optical Density per Foot of Smoke
** Irradiance in $\mu W/cm^2$, or Transmittance, T
*** Irradiance in $\mu W/cm^2$ at 1 Foot Distance, or δ

fourth line is the "Signal" in the third line converted to $\mu W/cm^2$ at the
distance of the measurement. The fifth line is the "inverse square of the distance"- conversion of the irradiance of line four to its value at a distance of 1 foot from the source.

In the cases where a negative value for "Signal" occurs in the third line, this is to be interpreted that the fire and its smoke attenuated the "Background" signal of the second line. In such cases, the "transmittance T" is recorded in the fourth line, and its corresponding "specific optical density "δ" is recorded in the fifth line. It may be possible to exploit this behavior by devising a method of using it as another tell-tale characteristic of a fire, particularly for a daytime background scenario.

Hence, comparing the nighttime irradiance value of the "UV PMT" column in Table 2, which is 6.1×10^{-4} $\mu W/cm^2$, with the daytime value in Table 3, which is 1.1×10^{-3} $\mu W/cm^2$, the true value of the fire irradiance is below the daytime background. It is only about 2.4% of the daytime measurement. The Spectronics 365 nm and 450 nm sensors likewise indicated the attenuation effect of the fire and smoke on the daytime background in those bands. In the case of the UV and IR fire detectors, here is an example where line two, the "Background" signal, did not indicate any signal at the UV and IR detectors until the fire was burning, despite the dominating daytime background, as line one shows.

The preceding example shows how the data of Table 2, which include the results from all four sites at Edwards AFB, are to be "walked through", line by line, for the UV and IR information recorded. Table 3, however, is only for the daytime JP-4 fuel burns which does not provide any useful JP-4 irradiance values other than to show that, where the measurement is "background limited", the flame and smoke had the observed attenuation effect on the daytime background. This "negative signal" does exhibit the flicker characteristic of a flame and its smoke attenuating the steady daytime background.

As summarized in Table 2, the JP-4 fuel burns provide the reference to which the values from all the other sources can be compared. A fire detector must be able to discriminate between the irradiance in the bands of interest, from that of one or more false alarm sources. Whether a single source is likely to cause a false alarm can be forecast from such a comparison. Also, by superposition of the irradiance values from any combination of such sources, it is possible to predict whether the combination is likely to cause a false alarm or not.

For UV fire detectors that use the 185 to 220 nm band for fire detection, the irradiances in the "UV PMT" column of Table 2 provide an excellent basis for forecasting likelihood of false

alarming. As stated earlier, every source measured with this system provided some level of signal. Regardless of the absolute value of each of these measurements, since the same instrument was used in all cases, the relative values enable a valid comparison to be made between the JP-4 fuel burn values and all the other values, whether singly or in combination. Likewise for any reflections, the percentage of reflected irradiance can provide values for estimating the impact of these in possibly causing a false alarm, once again either singly or in combination.

B. THE EFFECTS OF DISTANCE AND ATMOSPHERIC ATTENUATION ON SOURCE IRRADIANCES

The measured values tabulated in Tables 2 and 3 for the different sources and distances implicitly contain two attenuation effects:

(1) attenuation due to the distance inverse square law;

(2) attenuation due to the transmittance properties of the atmosphere for the different spectral bands.

To establish the relative likelihood of a particular source causing a false alarm, it is to compare its spectral irradiance values with those of burning fuels. The conditions of distance and atmospheric transmittance under which it will or will not cause a false alarm are likewise of equal importance.

It is therefore recommended, as mentioned above, that all measured values be brought to the same conditions of same distance and correction for atmospheric transmittance to enable proper comparisons to be made. In effect the absolute values of irradiance are derived in this way.

If, however, the effect of atmospheric attenuation is relatively small, but the distance attenuation is relatively large, application of the inverse square law alone to the measured irradiance value will provide a useful estimate of the absolute irradiance value.

If the effect of the atmospheric attenuation, however, is relatively large in the spectral band of interest, the combination of atmospheric and distance attenuation must be properly applied to derive the absolute irradiance value for comparison.

Tables 2 and 3 show that, for the same distance, the irradiances of the different sources and the irradiances of the different sizes of pan fires can legitimately be compared directly. This is because the distance and the atmospheric attenuation over that same distance are the same for all so being compared.

However, to convert all measured values to the same 1 foot distance for the UV band near 200 nm, and the IR band near 4.4 μm, careful consideration must be given to atmospheric transmittance as well as distance.

C. APPLICATION OF THE INVERSE SQUARE LAW TO THE MEASURED DATA

In any comparison, the first requirement is to establish the values at the same distance of interest. Since the irradiance E will vary inversely as the square of the distance x, and properly pairing E_1 with its distance x_1, and E_2 with its distance x_2, the simple equation for their relationship is:

$$E_1 X_1^2 = E_2 X_2^2$$

By appropriately introducing three of the known values into the equation, the fourth can be obtained. Hence:

$$E_2 = \left[\frac{X_1^2}{X_2^2}\right] E_1$$

Whether the irradiances are all brought to the same distance of 1 foot for comparison, or to any other preferred same distance, the comparison will be valid, provided atmospheric attenuation is small. A simple approach is to bring all values to a distance of 1 foot. In so doing, the denominator x_2 is 1 and therefore the value of E_1 taken from Table 2 needs only to be multiplied directly by the square of its distance to give the 1 foot distance value for E_2. Hence:

$$E_2 (at\ 1ft.distance) = E_1 X_1^2$$

Taking all the values of "UV PMT," and multiplying them by the square of their distance, gives distance adjusted values, but not transmittance adjusted values.

For example, the 25 foot value of UV irradiance of the 1 x 1 ft. pan JP-4 fuel burn is 6.1 x 10^{-4} $\mu W/cm^2$. When multiplied by the square of 25 feet, the irradiance at 1 foot distance is:

$$(6.1x10^{-4})(25)^2 = 3.8125x10^{-1}\mu W/cm^2$$

This value, however, needs to be adjusted for the atmospheric attenuation it went through over the 25-foot distance. This is discussed next.

D. APPLICATION OF THE LAMBERT-BEER-BOUGUER LAW FOR ATMOSPHERIC TRANSMITTANCE

In every case where light passes through a medium, the basic equation that defines the transmittance T_x is:

$$T_x = \frac{I_x}{I_0}$$

where I_0 is the intensity of light at the start of the path x, I_x is the intensity at the end of the path x, and T_x the total transmittance over the distance x.

It is equally valid to substitute irradiance for intensity in this equation, whereby:

$$T_x = \frac{E_x}{E_0}$$

where E_0 is the irradiance at the start of the path x, and E_x is the irradiance at the end of the path x.

This can be related more directly to the properties of the medium by taking account of the exponential attenuation as it relates to the specific optical density per unit distance of the medium over the distance of interest. Hence:

$$T_x = 10^{\delta x} = \frac{E_x}{E_0}$$

where δ is the specific optical density per unit distance, and x is the pathlength of interest. Hence:

$$\delta = \frac{\log \frac{1}{T_x}}{x}$$

Using the relations for atmospheric attenuation above:

$$E_x = E_0 T_x$$

or

$$E_0 = \frac{E_x}{T_x}$$

Combining the inverse square law with the Lambert-Beer-Bouguer law:

$$E_x = \frac{E_0 T_x}{x^2}$$

or

$$E_0 = \frac{E_x\, x^2}{T_x}$$

The spectral transmittance data through the atmosphere in the ultraviolet region from 200 to 300 nm, and in the infrared region from 4.37 to 4.42 μm, were obtained from Sverdrup Technology, Inc.. AEDC Group. The curves for transmittance versus wavelength for distances of 20, 50 and 100 feet are shown in Figure 9 (Reference 7) for the ultraviolet, and in Figure 10 (Reference 8) for the infrared.

The specific values of transmittance used here on the data measured at the different sites are:

Distance ft.	UV Transmittance (200 nm)	IR Transmittance (4.37μm)
20	0.1715	0.8383
50	0.0638	0.7359
100	0.0207	0.6274

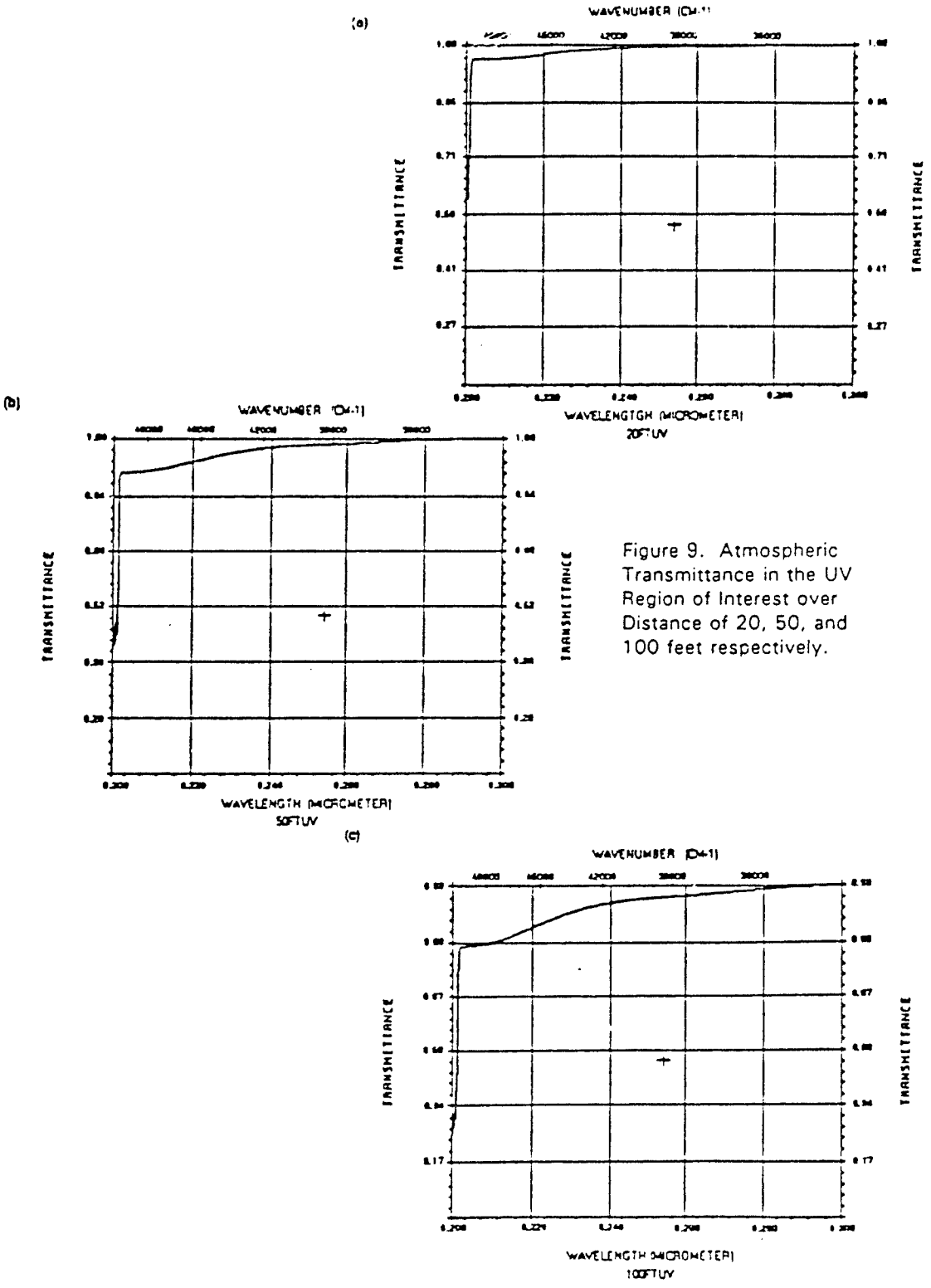


Figure 9. Atmospheric Transmittance in the UV Region of Interest over Distance of 20, 50, and 100 feet respectively.

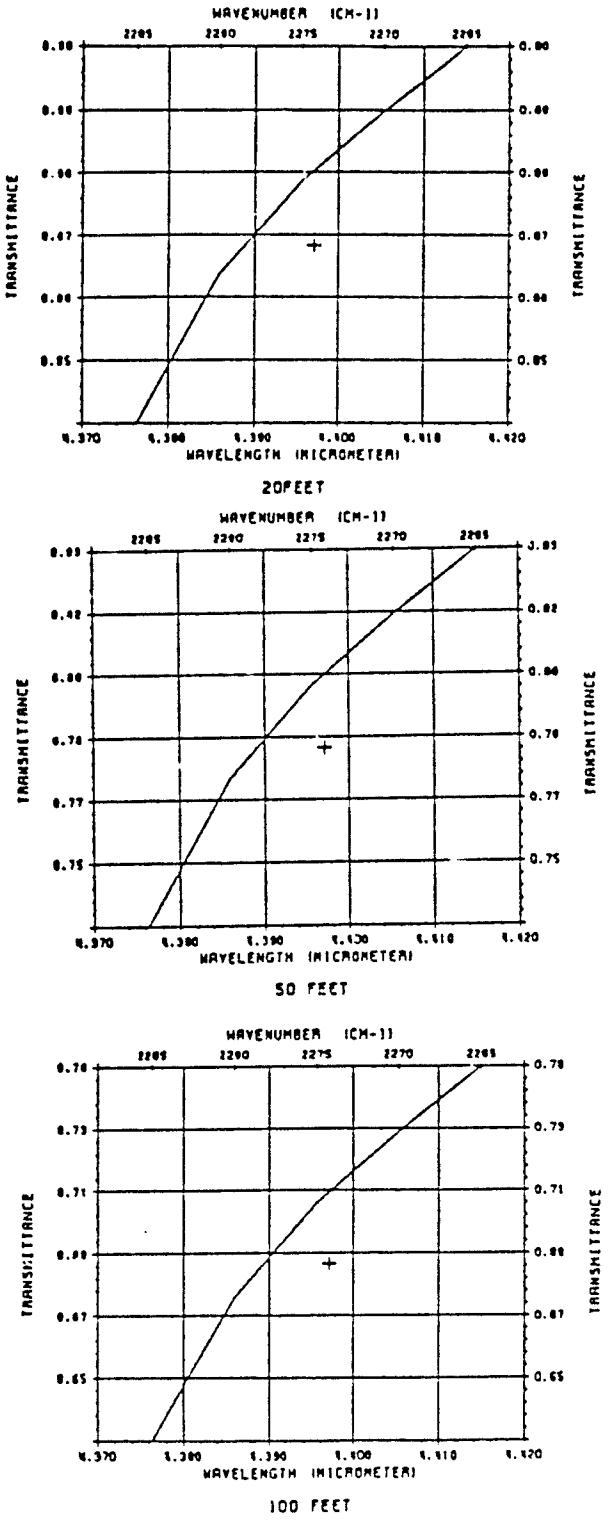


Figure 10. Atmospheric Transmittance in the IR Region of Interest over Distances of 20, 50 and 100 feet, respectively.

Hence, the absolute values of the measured irradiances from the different size JP-4 panfires at the different distances are:

Distance ft.	Measured Irradiance $\mu W/cm^2$	Absolute Irradiance at 1 ft. $\mu W/cm^2$
1 x 1 Ft. Pans		
25	6.1×10^{-4}	2.22
50	1.3×10^{-4}	5.09
100	4.4×10^{-5}	21.26
2 x 2 Ft. Pans		
50	5.5×10^{-4}	21.55
100	1.4×10^{-4}	67.63
4 x 4 Ft. Pans		
100	3.9×10^{-4}	188.41

Multiplying the irradiance of 5.51×10^{-2} $\mu W/cm^2$ at 4.5 feet distance from the welding of aluminum, and multiplying it by the square of 4.5 feet, the irradiance at 1 foot distance is:

$$(5.51 \times 10^{-2})(4.5)^2 = 1.1158 \times 10^{0} \mu W/cm^2$$

Assume the detector response threshold is set for a 2' x 2' JP-4 pan fire at 100', which is a common Air Force specification. Calculating the distance the Aluminum 6063, 4043 rod welding operation would have to be from the detector to yield an irradiance equal to the 2' x 2' JP-4 pan fire at 100 feet, it is obvious that the welding operation will cause the detector to respond in the UV if the welding operation is located at any distance from the detector up to about 90 feet.

Therefore, it becomes clear that a "false alarm" is a function of both the source irradiance at the source and the distance it is from the fire detectors. It would be useful to generate a whole family of curves of "source irradiance versus distance" to compare with the same for fuel fire irradiances for each possible false alarm source. This would serve to clarify at what distance a source will begin to cause "false alarm" problems, depending of course upon the threshold fire size and distance setting of the detector.

The same procedure for comparing the UV irradiances for establishing the likelihood of causing a false alarm is also to be applied to the IR irradiances in Table 2.

The data in Table 2, therefore, provide the baseline values that the fire detector designer must be able to discriminate a fuel fire from all of the potential false alarm sources detailed in Table 2, and from the additional sources to be discussed below. Depending on whatever spectral features the designer chooses to

exploit in his design, Table 2 gives a basic insight into what the competing irradiances of a major group of known false alarming sources are, and to which the fire detector designer must demonstrate immunity. The method of testing for this is a separate part of this document, and is given below.

SECTION V

CHARACTERISTICS OF POSSIBLE FALSE ALARM SOURCES

A. LIGHTS

The first category of false alarm sources are lights. The most likely lights to cause false alarms are the High Intensity Discharge (HID) lamps and Quartz Tungsten Halogen lamps found in aircraft shelters and hangars throughout the world. The portable Lightall Aircraft Ground Equipments also use HID lamps.

There are six basic types of hangar/shelter lights:

1. High Pressure Sodium (HPS), 1000 watts
2. Mercury Vapor, 1000 watts
3. Multivapor Metal Halide, 1500 watts
4. Multivapor Metal Halide, 400 watts
5. Fluorescent, typically 40 watts each
6. Quartz Tungsten Halogen, 300 watts up to 1000 watts

The lightall units are of two kinds: (1) two lamps, and (2) four lamps. The two-lamp unit has an old and a new version, which use the following lamps:

1. Old Version: Mercury Vapor, 400 watts

2. New Version: High-Pressure Sodium, 1000 watts

The four-lamp lightall unit uses:

1. Multivapor Metal Halide, 1000 watts

There are several manufacturers of these lights, each with their own versions. No attempt will be made here to define the minute differences between these versions. A representative version of each will be used here to describe their characteristic light output and behavior. It might be noted that, what is true for this category of lamps regarding different manufacturers, applies also to the other categories of lamps as well.

The behavior of the ballast can also be the scurce of the problem as well as the lamps themselves. This will be brought out to the extent possible in the following discussion. What will be shown is that if false alarms are to be reduced, it will also necessitate a critical review of all facilities for: (1) where the number of false alarms occur more frequently; (2) what are the specific types and manufacturers of lamps and ballasts used; and (3) whatever other details of behavior can be cited. Whether the effect is due to the lamp, or whether the ballast generating an EMI/RFI pulse has an effect on the power line, needs to be

determined. On this basis, only an "allowed list" of lamps and ballasts would be developed, applied and enforced. The research necessary to do this is beyond the scope of this contract.

1. HIGH PRESSURE SODIUM (HPS) LAMPS

Most AF hangars, such as at Edwards AFB, use 1000 watt High Pressure Sodium (HPS) lamps. The most common lamp at Edwards AFB is the GTE LU1000 Lumalux® HPS lamp. GE makes an equivalent LU1000 Lucalox® HPS lamp. Both use an ANSI specification S52 ballast. To help understand the behavior of this combination of lamp and ballast, their operation will be described briefly.

The lamp is made with two envelopes: (1) an inner envelope of translucent polycrystalline alumina which is the arc tube containing a small quantity of a sodium-mercury amalgam, and xenon as a starting gas; and (2) an outer borosilicate glass envelope which is evacuated and provides environmental protection, helps maintain the temperature, and prevents transmission of UV radiation out.

Light is produced by the electron current passing through sodium vapor in the following way. Voltage from the ballast is applied across the lamp. The "voltage" is a combination of the normal steady state voltage with a high voltage pulse superimposed. The pulse peak voltage for the 1000-watt lamp can swing from 4000 to 6000 volts. For other type HPS lamps, the pulse can swing from 2500 to 4000 volts. The pulse appears at least once per cycle for at least 1 microsecond at the peak of the steady state voltage wave.

The high voltage electric field across the xenon gas in the arc tube causes emission of electrons from the electrodes, which ionize the gas, putting it into a "glow discharge condition". The gas then breaks down fully going into an "arc discharge condition" between the electrodes. The heat of the arc progressively vaporizes the sodium and mercury amalgam.

During the warmup period, several changes occur in the color of the light. Initially, there is a very dim bluish-white glow produced by ionized xenon in the glow discharge condition. This is followed by the typical blue of the mercury glow which is brighter, and which remains a source of UV throughout the operation of the lamp. As the brightness increases, the color changes to monochromatic yellow which is characteristic of sodium when it is at a low pressure, as it is at this time. As the pressure in the arc tube increases with the temperature, the lamp comes to full brightness with its characteristic golden white light.

The high pressure sodium lamp is the most efficient of the HID family of lamps, radiating light across the visible spectrum. Under the relatively high pressure of the lamp (200

torr), the sodium radiation of its doublet "D" lines at 589 nm is self-absorbed. Because of the relatively high pressure, the gas emits a continuum of all visible wavelengths rather than single line emissions, with a dark region at the doublet lines where self-absorption occurs. This can be seen in Figure 11 (References 9, 10, 11), which will be discussed more fully below.

The mechanism of sustaining the arc discharge is very important. A brief consideration of Paschen's law, which applies to both the HID and fluorescent bulbs, will be helpful in understanding this aspect of gas lamp operational behavior, and how the ballast is important in sustaining the discharge. Paschen's law states that every gas breaks down into conduction at a particular voltage for a particular product value of its pressure p and its electrode spacing d. Hence, every "pd product" has its own "breakdown voltage". A study of gases shows in Figure 12 that a plot of "breakdown voltage versus the pd product" traces a "concave upward" curve, with its minimum breakdown voltage being at the bottom of the curve, and each higher breakdown voltage having two values of pd product either side of the uniquely single pd product corresponding to the "minimum breakdown voltage". As applied in the design of gas lamps, the electrode spacing is chosen to establish a particular set of breakdown voltages to fit a particular range of gas pressures. Since d remains fixed by design, as the pressure goes up, so does the voltage. As the pressure goes down, however, conversely the voltage goes up. The voltage optimum condition is when the pressure is right for the minimum breakdown voltage.

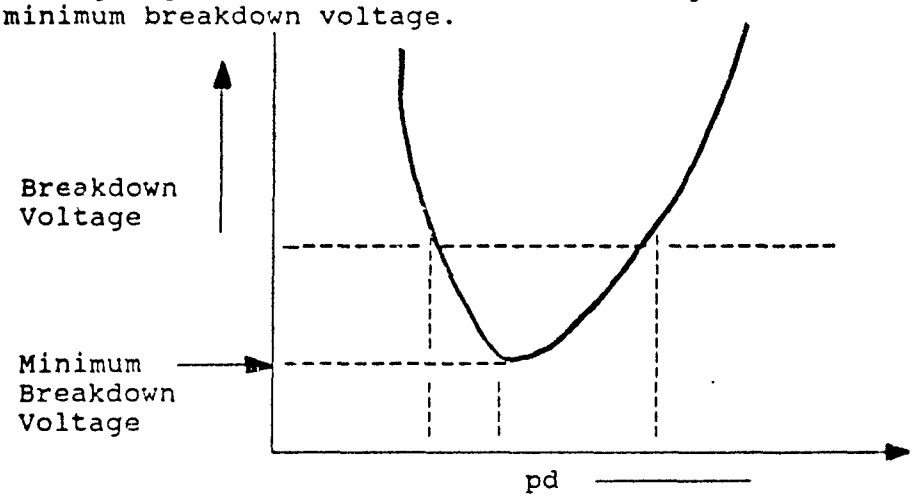
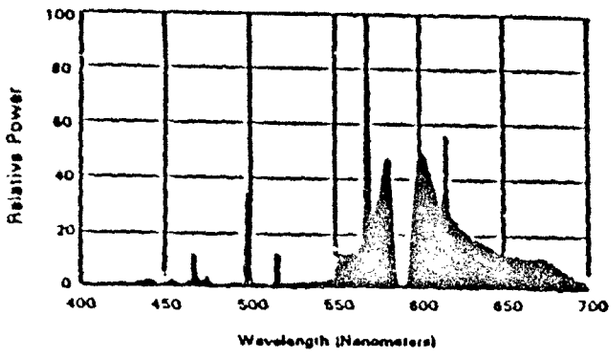
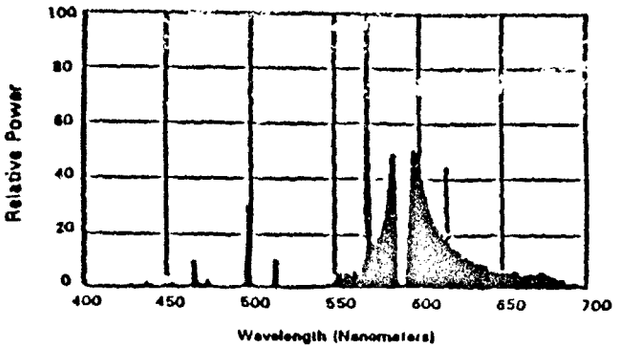


Figure 12 Paschen's Law

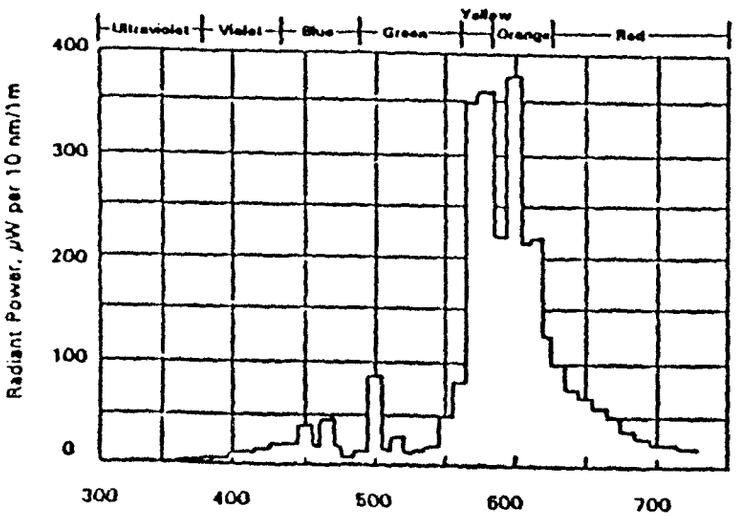
Understanding this law will help understand what happens during lamp warmup, and what is needed to restrike the arc when the lamp goes out, or when at end-of-life it begins to cycle on and off. The ballast is designed to automatically supply the proper voltages for transient eventualities up to its practical limit.



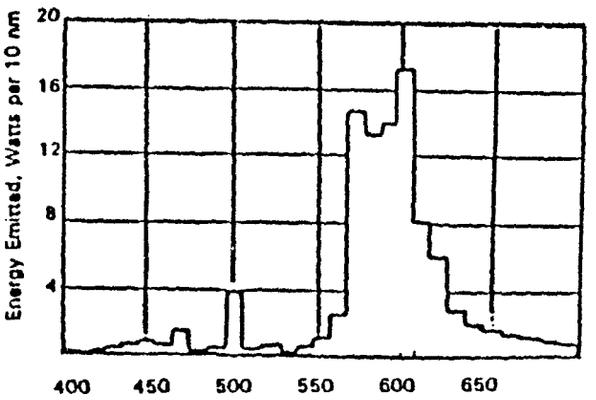
(a) Ceralux Lamps



(b) Ceralux-4 Lamps



(c) Spectral Energy Distribution of 400 Watt Lumalux Lamp



(d) Spectral Output of a 400-Watt Lucalox Lmap (GE)

Figure 11. High Pressure Sodium Lamps (HPS) Spectral Output

For instance, during warmup, which takes 3 to 4 minutes for the HPS lamps, once every half cycle the AC voltage goes to zero, effectively bringing the discharge to a shut-off condition. But the high voltage pulse will repeat every positive half cycle with the proper voltage, if needed, to sustain the discharge. A line voltage drop can cause this too. Figure 13 shows how line voltage variations can impact the different ballast types, causing appreciable variations in wattage operation of the lamps to higher or lower wattages and light outputs (Reference 12). Once in the full steady state operating condition, all pressures and temperatures are stabilized, which takes about 10 minutes. When the HPS lamp goes off, it takes about 1 minute to restrike the arc and bring it back to full brightness.

At the end-of-life point of the lamp, the voltage demand from the ballast is highest because of pressure conditions being too high, or too low, inside the lamp. The condition of cycling on and off is the point at which the ballast is at its voltage limit for sustaining the discharge. It sustains the discharge until the pressure rises with a corresponding higher voltage demand, which the ballast is unable to provide, and the lamp goes off. On cooling slightly, the pressure now drops, enabling the lamp to restart. It continues until the increased pressure and increased voltage demand once again causes it to shut off. This cycles on and off repeatedly until the lamp is replaced, which should be done to save the ballast.

As shown in these various transient states, it would be possible for such electrical irregularities to either produce EMI/RFI type radiation, especially with high voltage pulses, or effects in the electrical power line, that in turn could affect the fire detector's electronics or the electronic controller unit. In the arc discharge, high frequency electromagnetic radiation is being generated that can either transmit out directly, or along nearby wires, or in the power line itself. This is over and above what happens to the UV and IR irradiances produced by the lamp at those times.

One problem encountered in this program was the lack of availability of UV and IR spectral radiation data of the kind needed for the objectives of this program. There is no question that very high UV and IR radiation are produced in the arc tube part of all the HID lamps sufficient to trigger the fire detectors at any practical distance. However, the outer second enclosing borosilicate glass bulb used in HID lamps also serves to cut off the UV in particular, and the IR to a certain extent.

But the cutoff is not as complete as is expected. Borosilicate, or "hard" glass, used for its high temperature suitability for HID lamps, depending on its thickness, can transmit relatively high percentages of UV in the "near UV" region below 380 nm. Since a continuum of radiation is produced in the arc tube

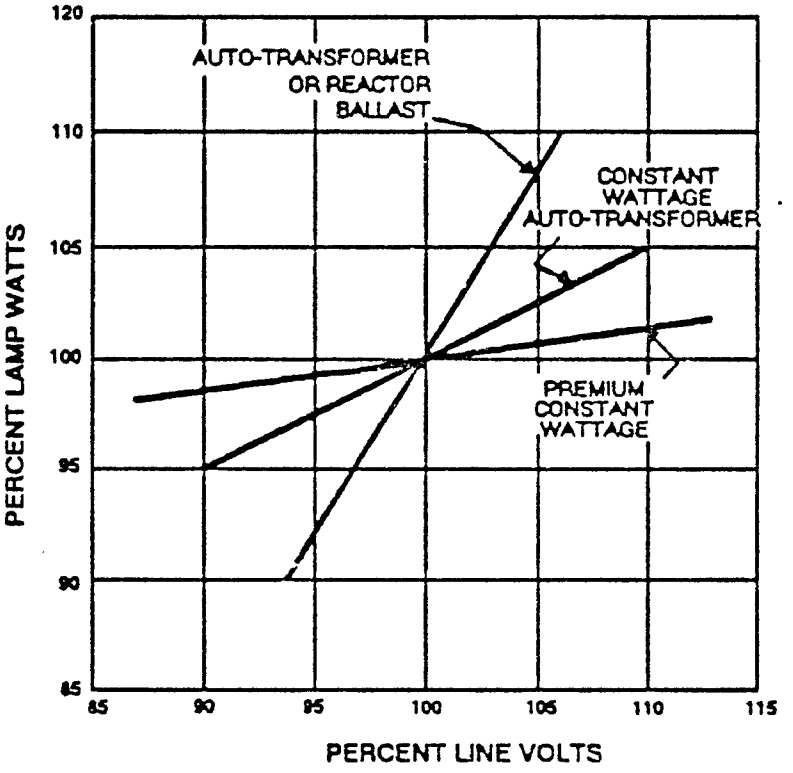


Figure 13. Effect of Line Voltage on Lamp Watts with Various Lamp Ballast Types

because of the high-pressure condition, in combination with the intense UV line of mercury vapor at 254 nm, a relatively high percentage of UV is emitted from the arc tube to the borosilicate outer bulb. The transmittance of the outer bulb below 380 nm does not begin to reach low values until around 300 nm. What is needed is to establish how much "deep UV" gets through, especially whenever transient events or irregularities occur as described above.

As discussed later in this report, these "deep UV" measurements were made with a UV photomultiplier system. Radiation and irradiation values were obtained at all transient and steady state operating conditions, with and without the protective glass lens covering. IR information was also obtained. Other supporting information was obtained from the manufacturers.

a. High-Pressure Sodium Spectral Output

To exemplify how two lamps that can serve the same application, but are made by two different manufacturers, can have spectral curves that are different, are shown in Figures 11(c) and (d). Figure 11(c) is that of the GTE Sylvania 400 watt Lumalux HPS lamp, whereas Figure 11(d) is of the GE 400 watt Lucalox HPS lamp.

The spectral distribution of the energy output of these particular 400-watt lamps is given in Table 4.

Table 4

Spectral Distribution of 400-Watt HPS Energy Output (Reference 13)

Visible Light	25.5%
Infrared	37.2
Ultraviolet	0.2
Conduction-Convection	22.2
Ballast	14.9

When 0.2% of 400 watts give an estimated total UV lamp output of 8.0×10^5 μW, the UV radiant intensity is estimated to be 6.37×10^4 μW/ster. At a 1 foot distance the UV irradiance is estimated to be 68.5 $\mu W/cm^2$.

Applying the same procedure to the 1000-watt HPS lamp, the total UV output is estimated to be 2.0×10^6 μW, the radiant intensity 1.59×10^5 μW/ster and the UV irradiance at 1 foot is 171 $\mu W/cm^2$.

How this irradiance is distributed in the several UV bands will be discussed later. Considering that the percentage of total UV radiance of the mercury vapor and metal halide lamps is about 10 times that of the HPS lamps, they could be more likely

"false alarm" sources than the high pressure sodium family of lamps.

The same determinations will be made for the IR bands of interest.

2. High-Pressure Multivapor Metal Halide Lamps

The metal halide lamp is the most efficient source of white light available today. It has a quartz arc tube which is slightly smaller than that of the same wattage mercury lamp. The arc tube contains argon gas and mercury, plus thorium iodide, sodium iodide and scandium iodide. These are the three major materials responsible for the performance of this light source.

Typical combinations of halides used in metal iodide lamps are: (1) sodium, thallium and indium iodides, (2) sodium and scandium iodides, and (3) dysprosium and thallium iodides. The spectral power distributions of some of them are shown in Figure 14 (Reference 15 and 16). Some halides, such as sodium (589 nm), thallium (535 nm), and indium (435 nm) principally produce line spectra, while others such as those of scandium, thorium, dysprosium and other rare earths produce multiline spectra across the full visible region. Other halides, such as those of tin, produce continuous spectra across the visible region. During the warmup period, the varying vaporization of these produces varying colors, and hence the designation "multivapor" lamps.

Once the arc is established, the lamp begins to warm up. As the warmup progresses, the metal additives begin to enter the arc stream and to emit their characteristic radiation. Because of the additives the sustaining characteristics of the ballast are more stringent than those required for a mercury lamp.

When the lamp is fully warmed, and the additive metals are in proper concentration in the arc, the spectral output of the lamp contains all the wavelengths to which the eye responds, giving the lamp an overall white appearance.

The spectral energy distribution of the multivapor metal halide family of lamps is the most important of the HID lamps for ultraviolet radiance. This is seen in Table 5.

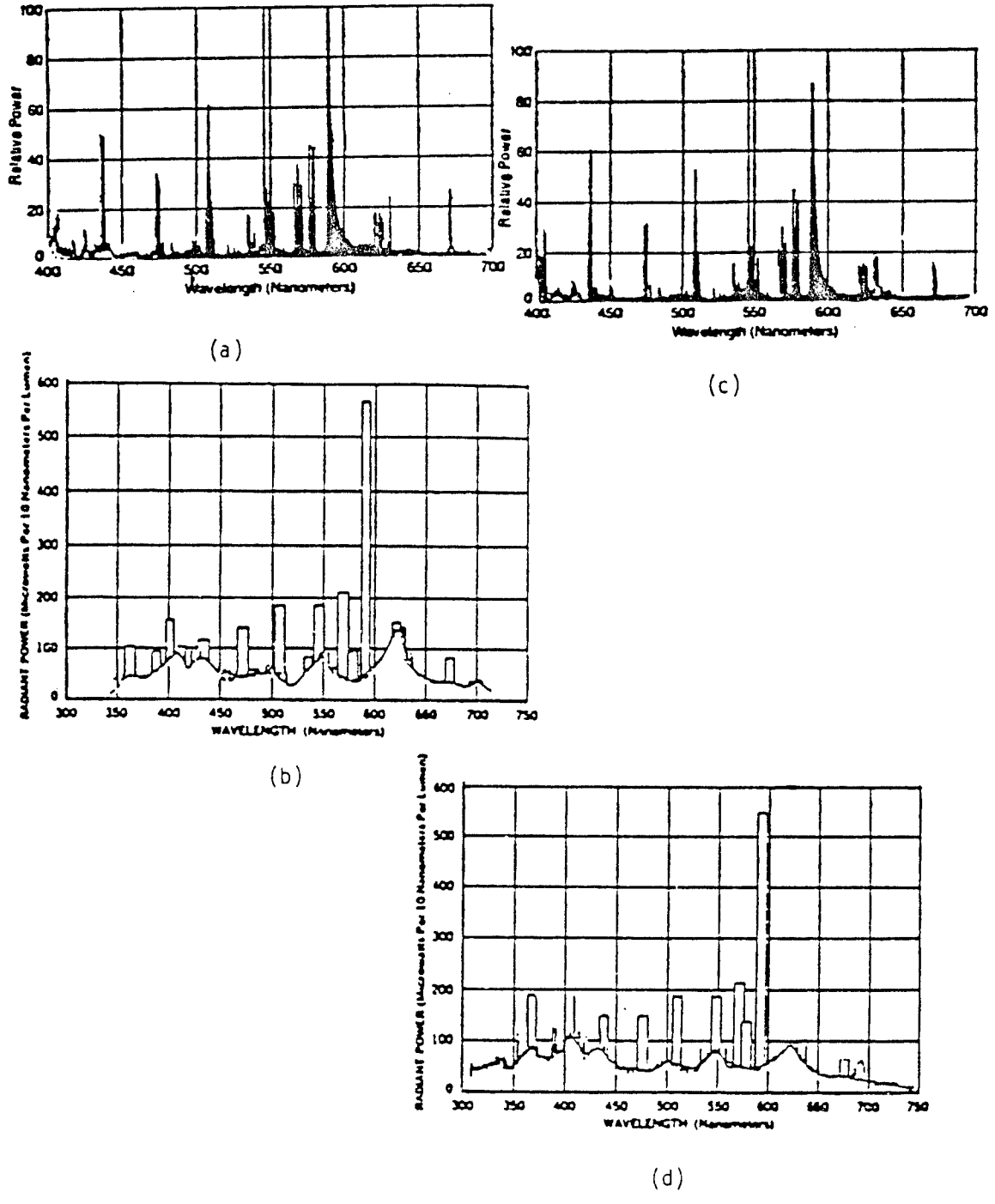


Figure 14. High Pressure Multivapor Metal Halide Lamps Spectral Output: (a) and (b): Metal Halide Lamps-Clear; (c) and (d): Metal Halide Lamps-Phosphor Coated

Table 5

Spectral Distribution of 400 Watt MH Energy Output (Reference 14)

Visible Light	20.6%
Infrared	31.9
Ultraviolet	2.7
Conduction-Convection	31.1
Ballast	13.7

As was stated above, Edwards AFB hangars also use two different types of metal halide lamps, and the mobile area lighting "Lightall" units a third:

1. GE MVT 400/I/U SAF-T-GARD Metal Halide lamp, 400 watts, with an ANSI specification M59 ballast, used in hangars;

2. GE MVR 1500/HBU/E Metal Halide lamp, 1500 watts, with an ANSI specification M48 ballast, used in hangars;

3. GE MVR 1000/U Metal Halide lamp, 1000 watts, with an ANSI specification M47 ballast, used in 4-lamp lightall unit.

The spectra of three metal halide lamps made by the same manufacturer with different power outputs are shown in Figures 15, 16 and 17 (Reference 17). Particularly noteworthy are the UV continuum and features below 400 nm, and the similarity of the entire spectrum for 400, 1000 and 1500 watt MH lamps in Figures 15, 16 and 17, respectively.

Estimating the ultraviolet radiance from the 400, 1000 and 1500 watt lamps, the values are determined to be as follows:

Table 6

Radiance, Radiant Intensity and Irradiance of 3 MH Lamp Powers

Parameter	400 watt MH Lamp	1000 watt MH Lamp	1500 watt MH Lamp
Total UV Radiance	10.80 W	27.00 W	40.50 W
UV Radiant Intensity	0.859 W/ster	2.149 W/ster	3.223 W/ster
UV Irradiance at 1 ft	925 $\mu W/cm^2$	2313 $\mu W/cm^2$	3469 $\mu W/cm^2$

The high level of UV irradiance from these three lamp wattages make them likely "false alarm" sources. Their UV and IR irradiances in the bands of interest were measured in the laboratory and will be discussed later.

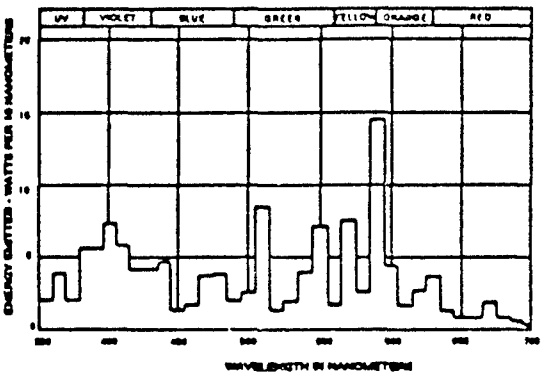


Figure 15. 400 Watt MH Lamp Spectral Output

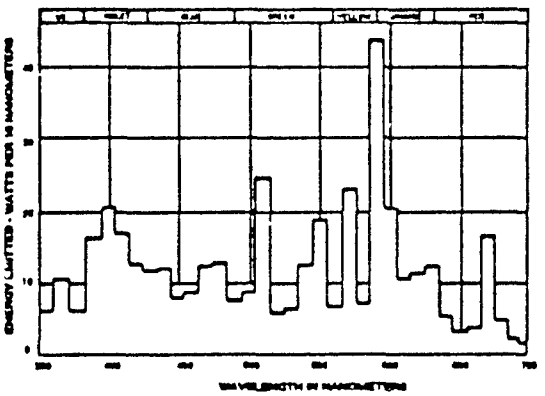


Figure 16. 1000 Watt MH Lamp Spectral Output

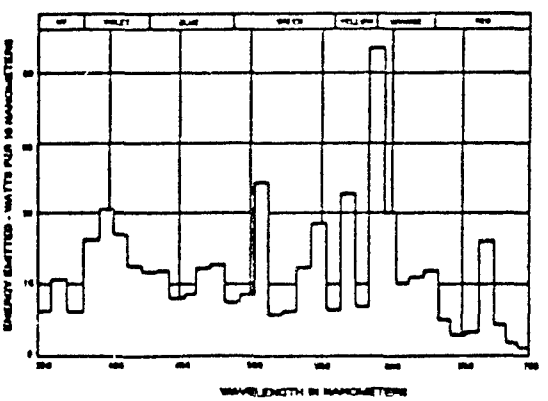


Figure 17. 1500 Watt MH Lamp Spectral Output

The warmup time for metal halide lamps can take up to 6 minutes. The restrike time can take up to 15 to 20 minutes, necessitating a period of cooling to reduce internal pressure before an arc is restruck again and grows to full brightness. This is one serious disadvantage to their use, unless temporarily substituted for by alternative backup sources as discussed below.

3. Mercury Vapor Lamps

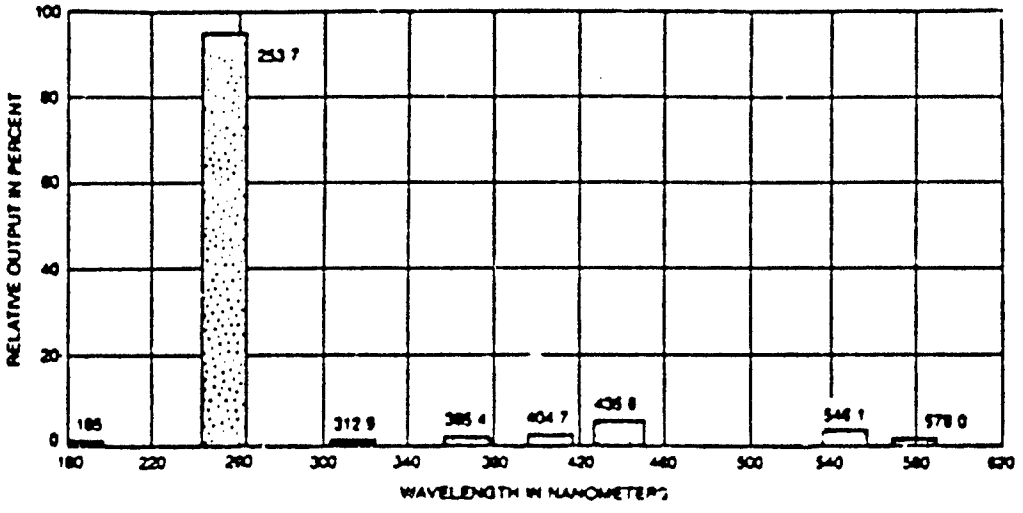
As with the other HID lamps, high-pressure mercury vapor lamps are made with an inner arc tube and an outer bulb. The arc tube is made of quartz. It therefore is highly transmissive in the UV region down to its UV cutoff well below 185 nm, and in the IR region up to its cutoff around 7 μm. It can itself be at temperatures as high as 1100°C, thereby producing considerable IR radiation, even in the 4.4 micrometer band. The outer bulb typically is borosilicate glass, likewise transmissive to its cutoff in the UV and IR regions.

Since mercury has a low vapor pressure at room temperature, and even lower at cold temperatures, a small amount of more readily ionized argon gas is introduced to facilitate starting. Once the arc strikes, its heat begins to vaporize the mercury, continuing until all the mercury is evaporated. The amount of mercury in the lamp (around 50 mg) essentially determines the final operating pressure, which is usually 2 to 4 atmospheres in the majority of lamps. Between the arc tube and outer bulb, an inert gas, generally nitrogen, is used to prevent oxidation of internal parts.

Ultraviolet radiation as applied to biological effects is divided into three regions: (1) UV-A or "longwave" ultraviolet from 320 to 400 nm; (2) UV-B or "shortwave" ultraviolet from 280 to 320 nm; and (3) UV-C or "extreme" ultraviolet from 180 to 280 nm. Figure 18 shows the relative spectral line distribution of energy emitted by ozone-producing germicidal low pressure mercury lamps (Reference 18). Such lamps have an enclosing bulb that is UV transmissive, and shows how the three UV regions relate in output.

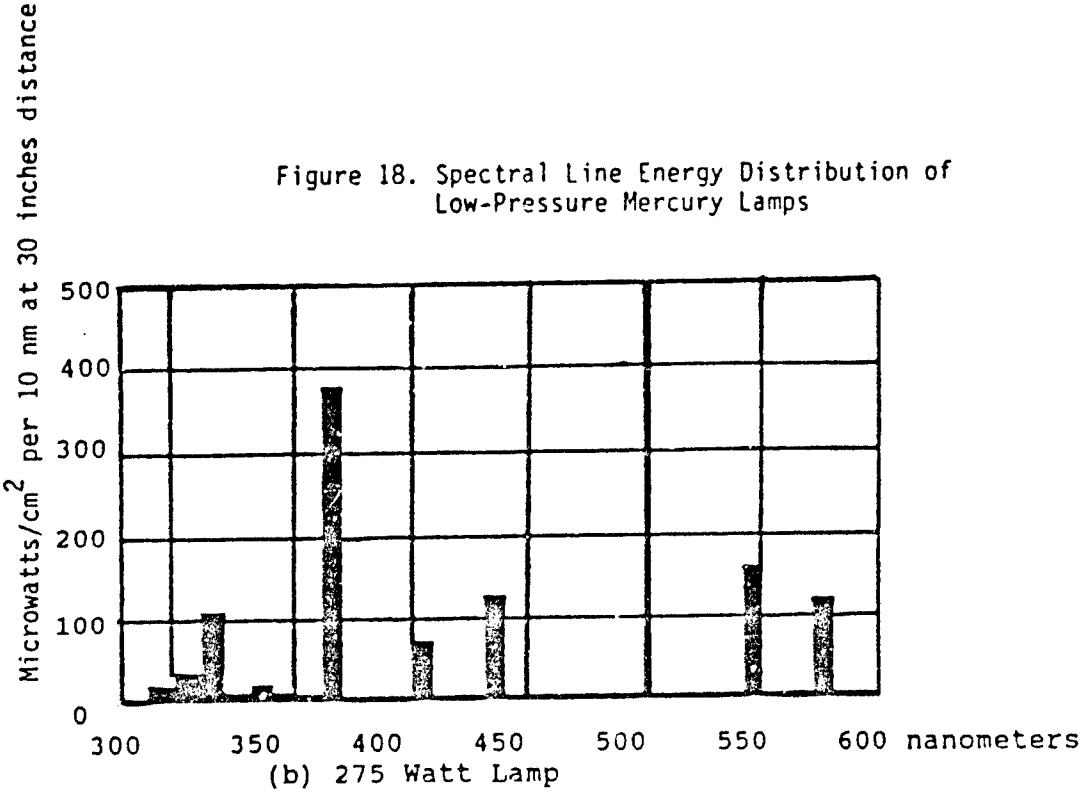
In the high pressure mercury vapor lamp, however, its pressure accounts for its characteristic spectral power distribution. In general, higher operating pressure tends to shift a larger proportion of emitted radiation into longer wavelengths. At extremely high pressure there is also a tendency to spread the line spectrum into wider bands. This is seen in Figure 19 (Reference 20). The use of borosilicate glass for the outer bulb also is to filter out the UV-B and UV-C radiation. The spectral output of various mercury lamps is shown in Figure 20 (Reference 21).

In the visible region, the five principal lines are at 404.7 nm, 435.8 nm, 546.1 nm, 577 nm and 579 nm, having the



(a) Relative Spectral Distribution of Energy Emitted by Ozone-Producing Germicidal Lamps

Figure 18. Spectral Line Energy Distribution of Low-Pressure Mercury Lamps



(b) 275 Watt Lamp

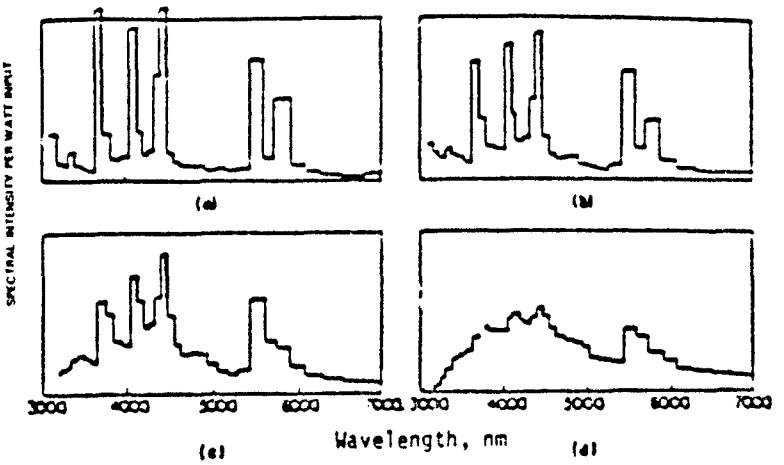
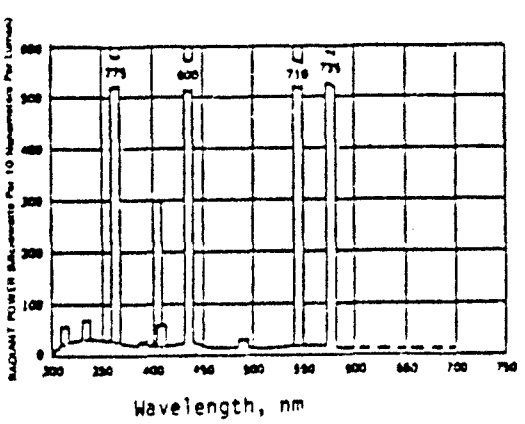
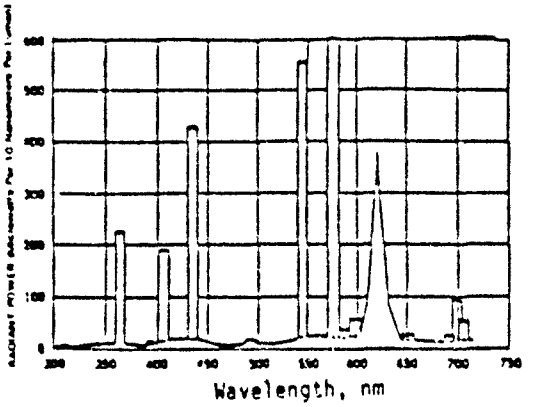
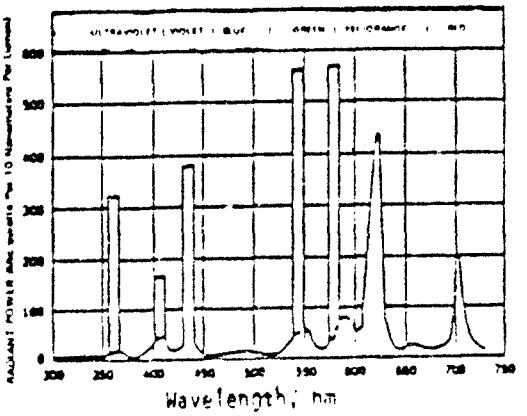


Figure 19. Emission Spectrum of High-Pressure Mercury Arc Lamps Showing Continuous Background: (a) 31 atm; (b) 75 atm; (c) 165 atm; (d) 285 atm. (Noel, 1941)







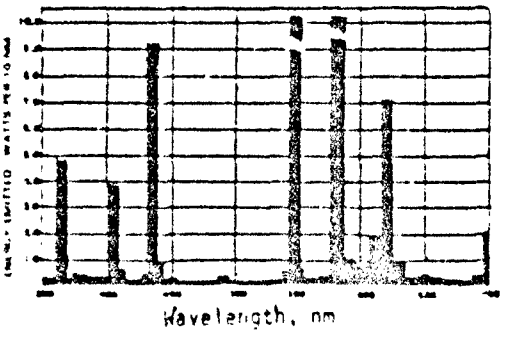


Figure 20. Spectral Output of High Pressure Mercury Lamps: (a) Clear; (b) deluxe, (c) Warm Deluxe; (d) Brite White Deluxe (H33GL-400 DX) as used in the Older 2-Lamp Lightall Units

appearance of a greenish-blue light. While the overall light appears to be bluish-white, an absence of red radiation, especially in the low and medium pressure lamps, causes blue, green and yellow colors to be emphasized whereas orange and red appear brownish. The "color-rendering" capability of mercury lamps is improved by coating the interior of the outer bulb with phosphors, similarly as is done in fluorescent lamps. This is done in the case of a mercury vapor HID lamp used in the older version of the lightall unit.

Designated as a Philips H33GL-400/DX lamp, a vanadate phosphor, which emits orange-red radiation, is used to coat the inner surface of the outer bulb. It results in a light output of white corresponding to 4000°K and hence the suffix "/DX" is added, which symbolizes a "deluxe white phosphor." This is shown spectrally in Figure 20(d).

One HID lamp that is a mercury vapor lamp used in the Edwards AFB hangars is the 1000 watt GE lamp: HR 1000 A36-15, to be used with the ANSI specification H15 or H36 ballast. It is a "clear" lamp without any phosphor coating.

The 400 watt mercury vapor lamp used in the older version 2-lamp lightall unit is a Philips lamp as described above, designated: H33GL-400/DX, to be used with the ANSI specification H33 ballast.

The energy output of the 400 watt mercury vapor lamp is:

Table 7 (Reference 22)

Type of Energy	400 Watt Mercury Vapor Lamp	
	Including Ballast	Excluding Ballast
Visible	14.6%	16.1
Infrared	46.4	51.1
Ultraviolet	1.9	2.1
Conduction/convection	27.0	29.7
Ballast	10.0	--

The UV radiance for the 400-watt lamp is about 7.6 watts, the radiant intensity is about 0.6046 watts/ster, and the irradiance at 1-foot distance is about 651 $\mu W/cm^2$. The IR radiance is about 204 watts, the radiant intensity about 14.77 watts/ster, and the irradiance about 1.59×10^4 $\mu W/cm^2$ at 1 foot.

For the 1000-watt mercury vapor lamp, the light output is about 2.5 times that of the 400 watt lamp. Scaling the above values accordingly, the UV radiance is estimated to be about 19 watts, the radiant intensity about 1.51 watts/ster, and the

irradiance about 1627 $\mu W/cm^2$ at a 1-foot distance.

Depending upon the distance, both lamps are capable of causing a false alarm in both the UV and IR regions.

The warmup time for the mercury vapor lamps is up to about 4 minutes. The restrike time is from about 3 to 10 minutes.

Because of the unique characteristics of HID lamps to require several minutes warmup time, to turn off with small drops in line voltage, and to require 1 to several minutes of restrike time to return to normal operation, it is advisable to supplement them with an alternative light source for such down times.

4. Fluorescent Lamps

The first major difference between the fluorescent lamps and the HID lamps is that they are low pressure gas discharge lamps. They also have a small amount of mercury to generate UV radiation for exciting the phosphors that coat the inner surface of the tubular lamps. They also have related warmup and restrike characteristics.

Fluorescent lamps are commonly in use in Air Force buildings, hangars and shelters. Their effect as false alarm sources is possible if the fire detectors are set to high sensitivity levels and if the lights are located close-by.

Divided into six basic types on the basis of white light output as determined by the phosphor coating, these are:

Cool White
Deluxe Cool White
Warm White
Deluxe Warm White
White
Daylight

Manufacturers frequently use commercial names for marketing purposes, resulting in a wide variety of lamp names. Table 8 summarizes several lamp types manufactured by GTE Sylvania, giving the spectral energy distribution. The variation in UV output below 380 nm is indicated. Figure 21 (Reference 25) shows the spectral output of several of these lamps.

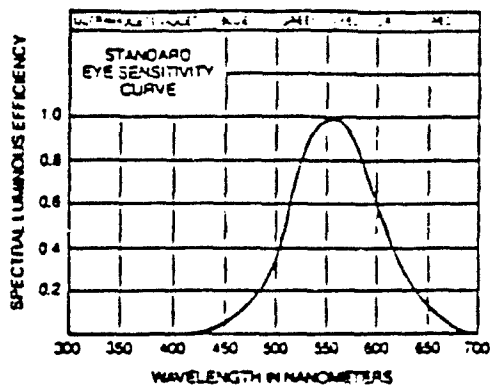
For estimation of the IR energy output, the summary of the spectral distribution in Table 9 (Reference 24) accounts for all the energy output of a Cool White lamp.

It was noted at Edwards AFB and at many European bases that the 96 inch fluorescent lamp was used extensively, and that

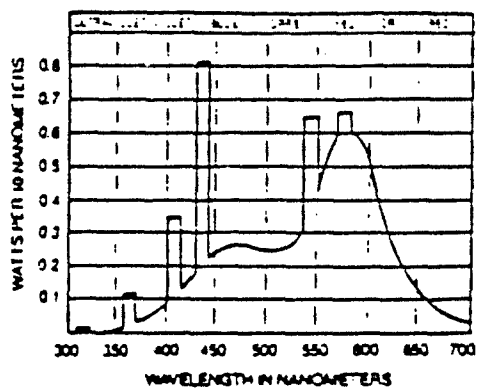
Table 8

Energy Emission of Selected 4-Foot Lamps in Arbitrary Color Bands in Watts

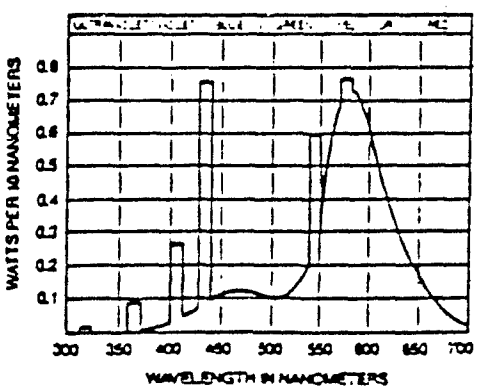
		37W T-12 Warm Lite Deluxe		34W T-12 Lite White Deluxe		40W T12 Royal White		40W T12 Cool White		40W T12 Warm White		40W T12 Daylight		32W T8 Ostron 31K		32W T8 Ostron 41K	
Band	Nanometers	watts	%	watts	%	watts	%	watts	%	watts	%	watts	%	watts	%	watts	%
Ultra-violet	< 380	.24	3.0	.22	2.7	.46	5.2	0.16	1.7	0.13	1.5	0.1%	2.1	.25	3.4	.23	2.9
Violet	380-430	.31	3.8	.41	4.8	.29	3.3	0.72	7.6	0.46	5.2	0.87	9.6	.28	3.8	.33	4.2
Blue	430-490	1.07	13.2	1.60	18.3	1.03	11.8	1.98	21.0	1.15	13.1	2.54	28.0	1.04	14.2	1.53	19.6
Green	490-560	1.90	23.5	2.29	27.6	2.23	25.8	2.35	24.9	1.8	20.6	2.49	27.4	1.81	24.7	2.35	30.2
Yellow	560-590	1.11	13.7	1.06	13.0	.80	9.2	1.74	18.4	2.06	23.5	1.32	14.5	.92	12.5	.72	9.2
Orange	590-630	2.86	35.8	2.06	24.8	3.10	35.8	1.60	17.	2.13	24.3	1.20	13.2	2.36	32.0	2.06	26.8
Red	630-700	.81	10.0	.64	7.7	.76	8.8	0.81	8.8	1.03	11.8	0.17	5.2	.06	8.4	.55	7.1
	Total	8.10	100%	8.29	100%	8.86	100%	8.45	100%	8.78	100%	9.08	100%	7.34	100%	7.8	100%



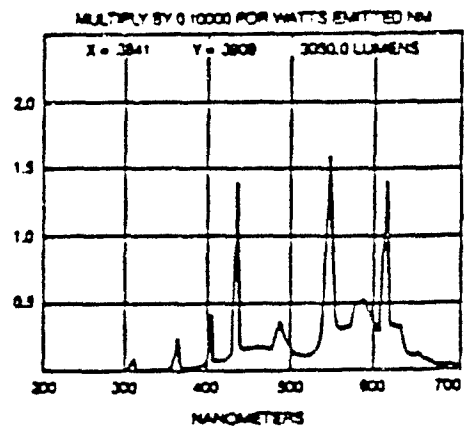
(a) Eye Sensitivity Curve



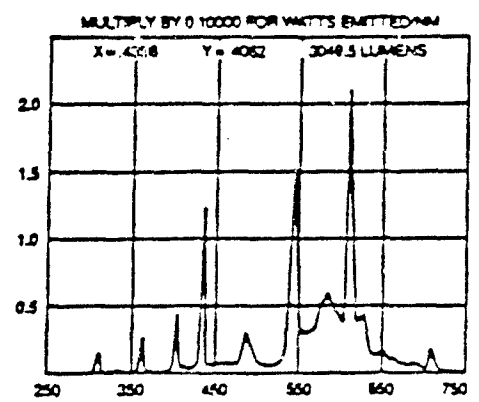
(b) Cool White F40CW



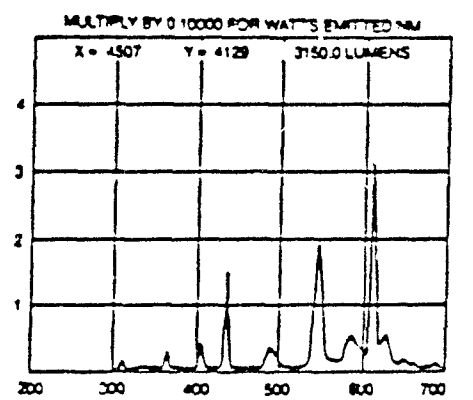
(c) Warm White F40WW



(d) Lite White Deluxe (LWX)



(e) Warm Lite Deluxe (WLX)



(f). Royal White (3K)

Figure 21. Spectral Output of Several Types of Fluorescent Lamps

the cool white type was used more commonly. But the warm white lamp also was used, sometimes in combination with the cool white lamp.

Approximately 60% of the input energy in a cool white lamp is converted directly into UV, with 38% going into the IR region, and only 2% into visible light. Figure 22 (Reference 26) shows how the input energy of a 40 watt fluorescent lamp partitions into the key energy types. The standard phosphor changes about 21% of the UV into visible light, the remaining 39% of the 60% UV being converted into IR.

Table 9

Energy Output for Some Fluorescent Lamps of Cool White Color [Lamps Operated at Rated Watts on High Power Factor, 120-Volt, 2-Lamp Ballasts; Ambient Temperature 25°c [(77°F) Still Air]

TYPE OF ENERGY	40WT12	96 INCH T12 (800 Ma)	PG17** (1500 Ma)	T12 (1500 Ma)
VISIBLE LIGHT	19.0%	19.4%	17.5%	17.5%
INFRARED (est.)*	30.7	30.2	41.9	29.5
ULTRAVIOLET	0.4	0.5	0.5	0.5
CONDUCTION-CONVECTION (est.)	36.1	36.1	27.9	40.3
BALLAST	13.8	13.8	12.2	12.2
APPROXIMATE AVERAGE BULB WALL TEMP.	41 C (106 F)	45 C (113 F)	60 C (140 F)	

* Principally Far Infrared (Wavelengths Beyond 5000 Nanometers).
** Grooves Sideways

The total 23% of the energy conversion into visible light for a 40 watt lamp turns out to be approximately twice the percentage for a 300 watt incandescent lamp, which changes only 11% of the input energy into visible light. The production of 36% IR by the fluorescent lamp compares with the 69% of a 300-watt incandescent lamp.

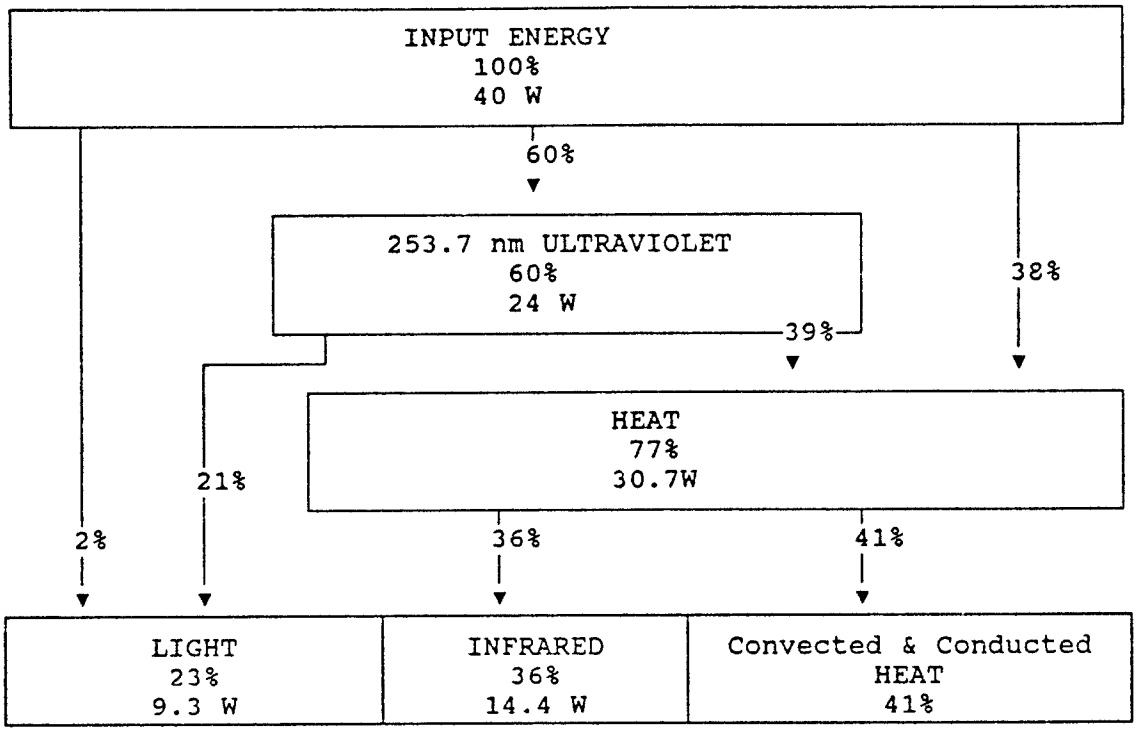


Figure 22. Energy Distribution of A Typical 40-Watt Cool White Fluorescent Lamp.

Besides the spectral continuum that a fluorescent lamp emits, it also emits narrow bands of energy. These are compared relative to each other in Figure 23 (Reference 10). Of particular note are the peaks at 185 nm and 253.7 nm, the spectral region exploited by some, if not all UV fire detectors. It is apparent that these specific emission "spikes" may influence a UV fire detector, or the UV sensor part of a multiple UV/IR detector, if the lamp is located close to the detector.

As low pressure near-equivalents of the HID family of lamps, the operational characteristics of fluorescent lamps likewise are similar. Their internal pressure is of the order of 1 to 3 torr, having mercury as the primary source for UV excitation of the phosphor coatings, but having a fill gas to facilitate the starting of the arc and maintain its steady state once established. The fill gas can be argon or neon, or sometimes xenon. Energy-saving lamps have a krypton gas fill.

In current use there are three different ways to start a lamp, but, in contradistinction to HID lamps, having very short start times. The three different methods, which result in three different types of ballast, are:

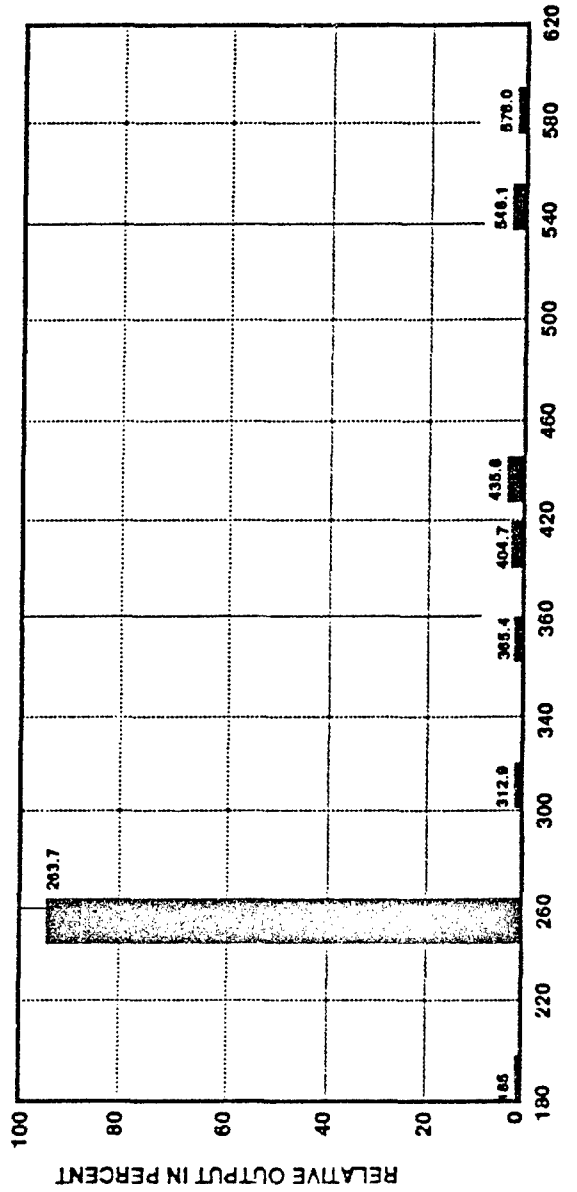


Figure 23. Relative Spectral Distribution of Energy Emitted by Ozone Producing Germicidal Lamps

(1) preheat: where the cathode filament, which serves as a thermionic emitter, is heated upon turn-on, and provides the electrons for striking the arc at the appropriate induced voltage. The starting time is several seconds, not minutes. This, however, is an old way.

(2) instant start: where a high voltage of the order 400 to 1000 volts is used to strike the arc quickly, the arc current serving to provide the heat to facilitate evaporation of the emission material. The start time is instantly upon turn-on. The ballasts used, however, are noisy during operation.

(3) rapid start: where the advantages of preheat and instant start are combined by keeping the cathodes heated during operation, and requiring a lower voltage. The start time is almost immediate, but with quiet operation, cheaper to operate and other advantages. It is the method in common use today.

In all cases, if a lamp goes off, the restrike time corresponds to the start time.

a. The Flicker and Stroboscopic Effect

A characteristic common to both the HID and fluorescent lamps is their capability to flicker as the result of their AC mode of operation. Even though the flicker of the light may not be seen visually, its effect on rotating or oscillating objects may result in seeing a stroboscopic effect, where no motion, or slow motion is seen while the opposite is true.

Since, in AC operation, the voltage goes to zero twice every cycle, there is the basic flicker that occurs 120 times a second when operated at 60 Hz. Another consideration is that every phosphor has a characteristic delay time which can have an impact on the light emission frequency. In short, operational factors of this kind are examples of temporal behavior which can be similar to flame flicker of a fire. As such, they could false alarm a fire detector which uses flame flicker as a fire specificity discriminant.

Table 10 (Reference 27) summarizes the percent flicker for the HID lamps with different ballasts, and Table 11 (Reference 28) gives the percent flicker for the six different "white" fluorescent lamps.

Table 10

Percent Flicker of Different HID Lamps with Different Ballasts

Lamp Type	Watts	Ballast Type	% Flicker (± 3%)	Flicker Index (± 10%)
Mercury	250	Reactor	88	.30
Mercury DX	400	Reactor	73	.25
Mercury	250	Lead-lag	25	.06
Mercury	400	Lead-lag	20	.05
Mercury	400	Regulator-Reactor	34	.10
Metal Halide (Na, Sc)	400	Reactor	38	.11
Metal Halide (Na, Sc)	1000	Reactor	34	.10
Metal Halide (Na, In, Tl)	1500	Reactor	28	.08
High Pressure Sodium	250	Reactor	95+	.29
High Pressure Sodium	400	Reactor	95+	.29
High Pressure Sodium	1000	Reactor	95+	.29
High Pressure Sodium	250	Lead-lag	50	.16

Table 11

Percent Flicker of Six Different White Fluorescent Lamps

	Single Lamp		2-Lamp Lead-Lag Instant Start		2-Lamp Lead-Lag Preheat Switch Start	
	Flicker Index	% Flicker	Flicker Index	% Flicker	Flicker Index	% Flicker
Cool white	.079	34	.071	26	.056	16
Deluxe cool white	.078	34	.075	27	.046	14
Warm white	.048	20	.044	16	.029	10
Deluxe warm white	.049	20	.043	16	.030	10
Daylight	.119	50	.107	41	.075	24
White	.058	25	.054	20	.042	12

b. Color Changes

Besides the color changes noted for HID lamps during warmup, and fluorescent lamps during normal operation, for HID lamps, where manual or automatic dimming control is used to either change brightness or conserve energy, one of the side effects is modification of color. The practice of automatic dimming for energy conservation is becoming more widespread.

High pressure sodium lamps generally provide their full output color down to about 50 or 60 % lumen output. Below 50% lumen output, a strong yellow color characteristic of low pressure sodium begins to prevail.

Metal halide lamps (clear) begin to fade at about 60% lumen output, where the characteristic blue-green color of mercury vapor starts to appear, and is distinctly apparent below 40% lumen output. The effect is less with phosphor coated lamps.

Clear mercury lamps change very little in color from 100% to 25% lumen output. The characteristic blue-green color of mercury is present at lower settings. Color improved lamps do well down to about 30% lumen output. Color changes are slower with HID lamps than with fluorescent lamps.

In the case of fluorescent lamps, temperature affects the color of the lamps. The color of the light from a fluorescent lamp has two components: (1) from the phosphor coating, and (2) from the mercury arc discharge within the lamp. Each reacts independently to temperature changes, shifting toward the blue-green with increasing temperature.

5. Incandescent Lamps

The incandescent lamps, especially the quartz tungsten halogen types, emit significant UV and IR across the spectrum and, as will be shown later, can cause false alarms, even to multiple wavelength detectors such as UV/IR.

The one component common to all incandescent lamps is the filament. Its resistance is driven by voltage and current into an incandescent condition, whereby its temperature is raised to the point where it emits visible light. As such, it is a "black body," which emits heat and light in accordance with the Stefan-Boltzmann law for radiance from a hot body. Strictly speaking, it is a "gray body" if the filament is tungsten, which does not have the emissivity of 1 of a black body, but rather around 0.3 at its high operating temperature. The percentage spectral energy distribution is the same at the temperature whether it is a "black" or "gray" body, but the radiance at each wavelength is proportionately less for a gray body relative to a black body.

Secondary to the filament as the key element in an incandescent lamp is the enclosing bulb, which can be of any shape and finish. Contingent upon the operating temperature, the bulb material and thickness used, and any other special application requirements, will be dictated accordingly. Soft glass is generally used. Hard glass is used for some lamps to withstand higher bulb temperatures and for added protection against bulb breakage due to moisture.

Passing electric current through the filament, and against the filament resistance, consumes electrical power which heats the filament to incandescence. This conversion step of electrical energy to electromagnetic radiation energy, and more specifically to visible light energy, has a certain efficiency which depends on certain parameters. The term used for every lamp is its "efficacy," which is the ratio of its light output in lumens relative to the power input in watts.

Efficacies of 23 lumens per watt are commonplace in larger commercial type incandescent lamps. Projection lamps have efficacies up to 33 lumens per watt, and photographic lamps reach 36 lumens per watt.

Although carbon theoretically could have the highest efficacy of all, since it has the highest "melting point" of any known element, which is 3823°K (3550°C, 6422°F), at which it sublimes into gas rather than melts, this was its principal limitation. It could not be operated at a high enough temperature to obtain the desired efficacy without rapid evaporation, shortening the lamp life. Osmium and tantalum replaced it partly for awhile, until tungsten replaced it almost completely.

Tungsten wire has great strength and durability, and is the best material because it can be heated to very near its melting point of 3655°K (3382°C, 6120°F) without evaporating rapidly. As the operating temperature is increased, the light output and efficacy are increased.

Theoretically, tungsten should yield an efficacy of 52 lumens per watt at its melting point, but the practical limit is about 36 lumens per watt because of losses within the lamp. To reach this efficacy, the life of the lamp is shortened to only eight or ten hours.

Tungsten halogen lamps are the brightest of the incandescent family of lamps. Their unique characteristics are applicable in any size lamp, from the smallest to the largest incandescent lamps. One particular feature enables these to have the highest efficacies among incandescent lamps, while operating at the highest temperature, yet having a longer life than lamps without this unique feature. It is the "halogen regenerative cycle" that makes this possible.

Tungsten halogen lamps were originally called "iodine quartz lamps" since iodine was the original halogen used inside a tungsten filament lamp with a quartz tube bulb. Since bromine, another halogen element, came to be used in place of iodine in some lamps, the broader designation of tungsten halogen lamps was adopted.

The halogen regenerative cycle works quite effectively. In a standard incandescent lamp, tungsten particles evaporate from the hot filament, and are carried by convection currents to the relatively cool bulb wall, with time building up a black deposit which blocks the light output. However, if iodine is inside the bulb, as the bulb temperature rises, the iodine vaporizes. The tungsten particles and iodine vapor combine to form tungsten iodide. Since the bulb wall temperature must exceed 250°C (523°K, 482°F) to maintain effective operation of the iodine-halogen cycle, a small diameter quartz tube is used as the bulb. Quartz has a melting point of 1650°C (1923°K, 3002°F) which makes it suitable for the extreme heat from high wattage filaments, as well as meeting the temperature requirements of the halogen cycle.

Operation at bulb wall temperatures of 250°C to 1200°C is readily achieved in small diameter tubular quartz lamps. When tungsten iodide forms in the vicinity of the hot bulb wall, convection currents carry the iodide back to the filament where the temperature is over 2500°C (2773°K, 4532°F). The high temperature breaks down the iodide, tungsten redeposits on the filament, and the free iodine vapor recirculates to continue the regenerative cycle.

This cycle keeps the bulb wall clean and results in a much higher lumen maintenance than obtained with a conventional incandescent lamp. The lamp life would be much longer if the tungsten redeposited evenly on the filament. However, since it does not, it ultimately develops a thinner section and fails the same as a conventional incandescent lamp.

For certain types of tungsten halogen lamps, especially for photographic and reprographic applications, bromine is used instead of iodine. Bromine enables the halogen regenerative cycle to operate at a minimum bulb wall temperature of 200°C (473°K, 392°F), reaching an operating temperature sooner than with iodine. Also, since bromine is relatively colorless, it increases light output by 3% to 5%. Iodine, however, will continue to be used in most standard tungsten halogen lamps.

The spectral energy distribution of tungsten halogen lamps and standard incandescent lamps is similar as shown in Table 12 (Reference 29).

Iodine vapor absorbs slightly in the green band, causing a tungsten-iodine incandescent lamp to have a very slight purplish

tinge. Since red and blue light as primary colors mix to produce purple light, the effect is as expected. It is noticed for a few

Table 12

Approximate Spectral Energy Distribution of Incandescent Lamps

Visible Light	10-12%
Infrared	70%
Ultraviolet	0.2%
Conduction-Convection	19%

seconds after the lamp is turned on, and while the iodine is condensing in the lamp after it is turned off. When bromine is used instead, a whiter light is produced with no tendency to appear purplish.

The one characteristic that all incandescent lamps have in common is their relationship to "blackbody" radiation. Where HID lamps produce light by means of high voltage excitation of gases and fluorescent lamps by the UV excitation of luminescence from phosphors, the incandescent lamps produce it by making the filament operate at very high temperatures.

It is this fact that introduces the particular wavelength dependence of the emissive properties of a filament on its light output. Every material has its own characteristic emission as a function of temperature.

No known radiator, however, has the same emissive power as a blackbody. The ratio of the output of a body at any wavelength to that of a blackbody at the same temperature and the same wavelength is known as the spectral emissivity, $\epsilon(\lambda)$, of the radiator. For a true blackbody, this value would be 1 across all wavelengths.

If the value of the spectral emissivity were to be less than 1, but be constant across all wavelengths, this would define the radiator as a "graybody". However, there is no known radiator that has a constant spectral emissivity for all visible, infrared and ultraviolet wavelengths. A carbon filament comes closest, having a very nearly uniform emissivity in the visible region, making it nearly a "graybody."

For all other materials, however, the emissivity varies with wavelength, and are designated "selective radiators." Tungsten is such a material.

Figure 24 (Reference 30) shows the radiation curve for a blackbody, a graybody and tungsten as a selective radiator, all operating at 3000°K. Of particular note are: (1) the radiant power at 4.3 μm, and (2) the same as far as the curve goes into the

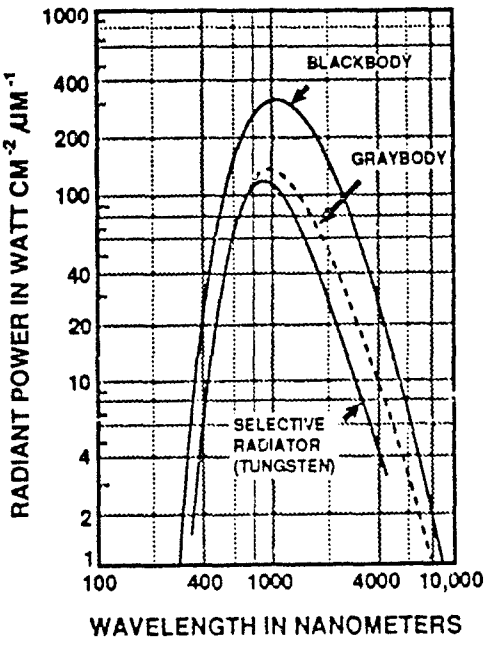


Figure 24. Radiation Curves for Blackbody, Graybody, and Selective Radiators Operating at 3000°K.

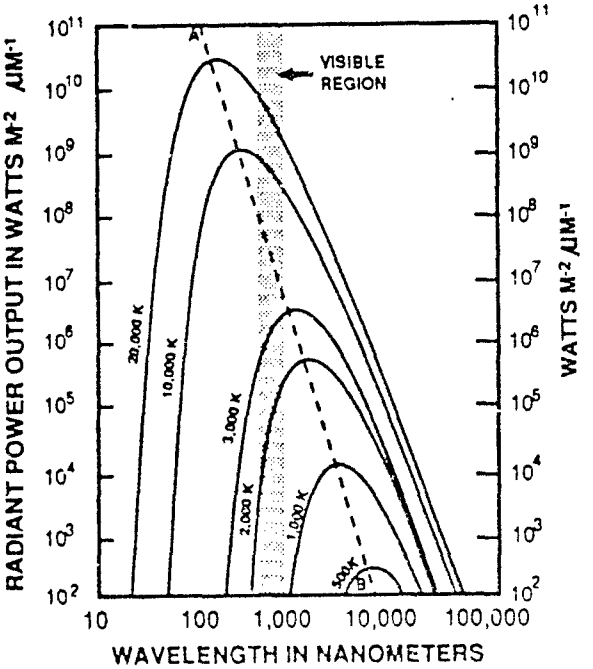


Figure 25. Blackbody Radiation Curves for Operating Temperatures between 500°K and 20,000°K Showing Wien Displacement of Peaks. Shaded Area is Region of Visible Wavelengths.

ultraviolet. Being a log-log plot, there is no zero, implying that both wings of the curves continue on to lower radiant powers and other wavelengths. Figure 25 (Reference 31) shows a family of blackbody curves for the temperatures from 500° to 2000°K.

A blackbody curve for 2700°K approximates the radiation from burning propane at 4.3 μm, which in turn is a near equivalent to the same wavelength of burning JP-4 fuel. Figures 26 and 27 show the blackbody radiation curves for a temperature at 2700°K, extending into the ultraviolet range of interest as well as the infrared. Table 13 shows the tabulated data for these curves.

Review of Table 13 shows that the irradiance from the filament of an incandescent lamp from 180 nm to 220 nm in the ultraviolet is capable of exceeding the corresponding values for burning JP-4 fuel given in Table 2. Similarly, the value at 4.3 μm in the infrared is higher than that obtained from the JP-4 fuel burns summarized in Table 2.

Since the bulb for lower wattage lamps attenuates these spectral irradiances considerably, which are further attenuated by the atmosphere and distance, they are less a false alarm threat than high wattage lamps. The tungsten halogen lamps with either quartz, fused silica or borosilicate glass bulbs, however, have higher transmittances in these regions, as well as producing higher radiance at the filament than other incandescent lamps. As is apparent, they present a serious problem in endeavoring to establish immunity of fire detectors against them.

It can be expected that many types of incandescent lamps, and especially the quartz tungsten halogen lamps will cause false alarms at certain wattages, distances, and atmospheric conditions.

To obtain an overall sense of incandescent lamps regarding their full range of filament operating temperatures, and bulb temperatures, and their light output, the following Tables and Figures provide the information.

Table 14 gives the filament temperatures and their associated light output characteristics for standard 120 volt incandescent lamps for power values ranging from 6 watts to 1500 watts. The maximum bare-bulb temperatures for these are given in Table 16. Figure 28 gives the relative spectral energy output in the visible region from tungsten filaments of equal wattage, but across the whole spectrum of absolute operating temperatures. To the extent that it has been summarized above, what comes through the bulb will be determined by the spectral transmittance properties of the bulb.

6. Summary of Lamps

Table 16 summarizes important lamps of all

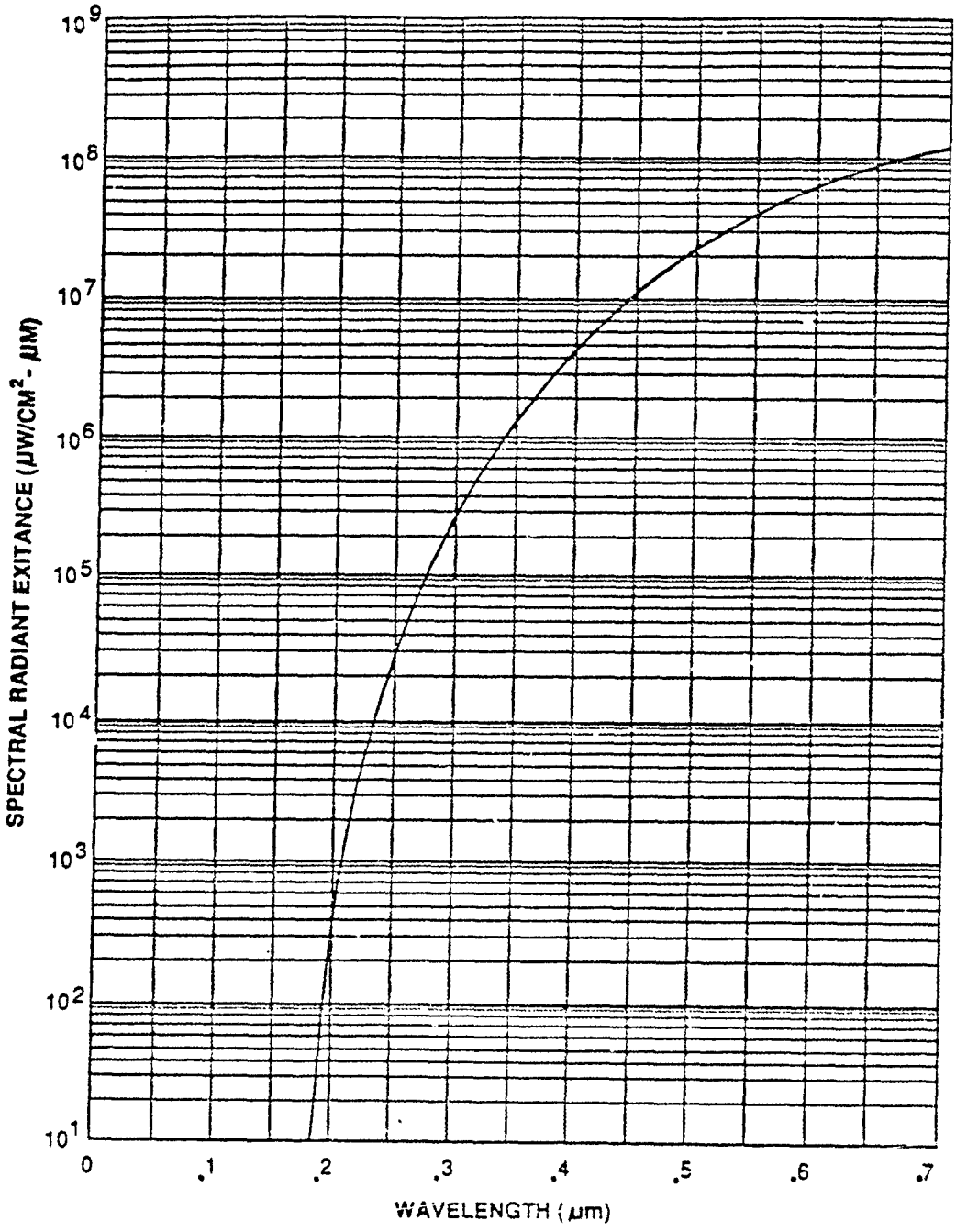


Figure 26
BLACKBODY RADIATION
CURVE AT 2700°K

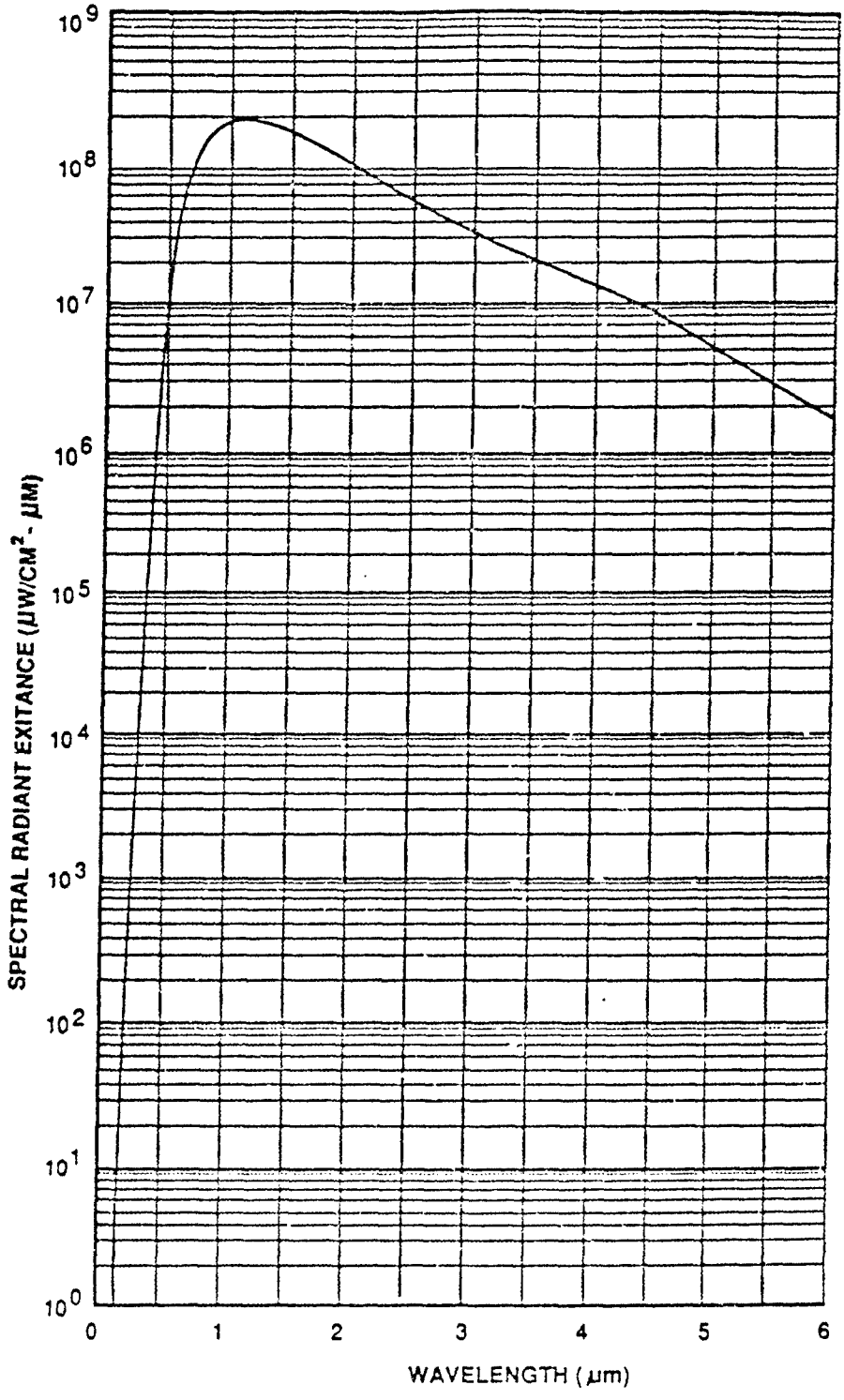


Figure 27
BLACKBODY RADIATION
CURVE AT 2700°K

Table 13

Blackbody Spectral Radiant Exitance
Temperature = 2700°K
Peak Wavelength = 1.07μm
Emissivity = 1.0

Wavelength μm	Spectral Radiant Exitance μW/cm²-μm	Wavelength μm	Spectral Radiant Exitance μW/cm²-μm
Ultraviolet		Visible	
0.180	6.68×10^{0}	0.380	3.36×10^{-1}
0.200	4.38×10^{0}	0.400	2.74×10^{-1}
0.220	2.99×10^{0}	0.420	2.25×10^{-1}
0.240	2.11×10^{0}	0.440	$x.27 \times 10^{-1}$
0.260	1.53×10^{0}	0.460	1.57×10^{-1}
0.280	1.14×10^{0}	0.480	1.32×10^{-1}
0.300	3.66×10^{-1}	0.500	1.12×10^{-2}
0.320	6.69×10^{-1}	0.520	9.60×10^{-2}
0.340	5.25×10^{-1}	0.540	8.25×10^{-2}
0.360	4.18×10^{-1}	0.560	6.20×10^{-2}
Infrared		0.580	5.41×10^{-2}
0.800	1.71×10^{-2}	0.600	5.41×10^{-2}
0.900	1.07×10^{-2}	0.620	4.74×10^{-2}
1.00	7.02×10^{-3}	0.640	x^{x}
2.00	4.39×10^{-4}	0.660	3.69×10^{x}
3.00	8.67×10^{-5}	0.680	3.28×10^{-2}
4.00	2.74×10^{-5}	0.700	2.92×10^{-2}
4.30	2.05×10^{-5}	0.720	2.61×10^{-2}
5.00	1.12×10^{-5}	0.740	2.34×10^{-2}
6.00	5.42×10^{-6}	0.760	2.10×10^{-2}
		0.780	1.89×10^{-2}

categories regarding wattage, rated average life, approximate initial lumens and approximate initial efficacy in lumens per lamp watt.

The terms "color temperature" and "color rendering index" need clarification, since they can be easily misunderstood and be misleading.

Color temperature is a parameter frequently given for any kind of light source where the color of the light comes close to that of a blackbody at the designated temperature, and which would be defined for its color characteristics on a chromaticity diagram accordingly. It is not the absolute temperature of the filament, but is related to it to the extent that, as the filament temperature goes up, so does the color temperature go up.

Table 14

Filament Temperatures and Efficacies of 120 Volt Incandescent Lamps

Lamp Watts	Bulb Size	Approx. Filament Temp. °F.	Approx. Filament Temp. °K.	Approx. Color Temp. Kelvin	Approx. Initial Lumens	Efficacy Lumens per Watt
6*	S-14	3860	2399	2370	40	6.5
10*	S-14	3900	2422	2450	86	8.0
25*	A-17	4190	2583	2550	235	9.4
40	A-17	4470	2739	2770	460	11.5
60	A-17	4530	2772	2800	890	14.8
100	A-17	4670	2850	2870	1750	17.4
150	A-21	4730	2872	2900	2850	19.2
200	A-23	4760	2899	2930	3940	19.7
300	PS-30	4830	2939	2940	6000	20.0
500	PS-35	4840	2944	2960	10600	21.0
1000	PS-52	4980	3022	3030	23100	23.1
1500	PS-52	5010	3039	3070	33620	22.4

*Vacuum

The "color rendering index" refers to the fact that each kind of lamp illuminates different colored objects differently. Two "white light" lamps, because of the spectral content of their emitted light, can result in shades or tones, or even colors of

reflected light from colored objects being visually different. For instance, lighting a red object with a mercury arc lamp will cause the object to appear black or gray. Hence, to aid lighting engineers to choose proper lamps for illuminating garments, for instance, in a clothing store, the CRI of a lamp aids in making a proper choice. The higher the CRI, the nearer the lamp is to true "white light".

Not only is the color temperature higher for lamps of greater efficacy, but for any particular lamp the color temperature increases with line voltage.

These two parameters, color temperature and color rendering index, are of no consequence in hangar lighting.

Table 15

Maximum Bare-Bulb Temperatures of Standard Incandescent Lamps*

Watts	Bulb	°Fahr.	°Kelvin
25	A-19	110	316
40	A-19	260	400
60	A-19	255	397
100	A-19	300	422
150	A-23	280	411
200	A-23	345	447
300	PS-30	385	469
500	PS-35	415	486
1000	PS-52	480	522
500	PS-52	510	539

*Bare lamp burning vertically, base up.

This Table (Reference 34) shows that lamp bulb temperatures are considerably below the safe operating maximum of 700°F for soft glass.

B. REFLECTED LIGHT

Besides the direct light from any false alarm source, the possibility of its reflected light adding to its direct light to trigger a fire detector system is considerable. As is seen in Table 17 (Reference 36), the reflectance of UV in the region of

mercury's strong wavelength at 253.7 nm is relatively high from a variety of surfaces.

Table 16

Efficacies of Illuminants (Reference 35)

The theoretical maximum efficacy of 680 lm/W is that which would be obtained if all the power input were emitted as green light at a wavelength of 555 nm (at which the eye is most sensitive). If all power could be emitted uniformly over the visible spectrum as white light, the efficacy would be of the order of 220 lm/W.

Fluorescent life-ratings are based upon 3 hours of operation per start. Life increases as lamps are burned for longer periods.

Lamp	Lamp watts	Rated average life, hours	Approx. initial lumens	Approx. initial efficacy, lm/lamp W
A. Tungsten filament (120 V)				
Vacuum	25	2,500	235	9.4
Gas filled	40	1,500	455	11.4
Gas filled	60	1,000	870	14.5
Gas filled	75	750	1,190	15.9
Gas filled	100	750	1,750	17.5
Gas filled	200	750	4,010	20.1
Gas filled	500	1,000	10,850	21.7
Gas filled	1,000	1,000	23,740	23.7
Gas filled (3,200 K)	5,000	150	145,000	29.0
Gas filled (3,200 K)	10,000	75	335,000	33.5
B. Fluorescent (cool white)				
Preheat (T12)	20	9,000	1,300	65.0
Rapid start (T12)	40	20,000	3,150	78.8
Rapid start (T12, shielded cathode)	40	15,000	3,250	81.3
Rapid start (T12, U shaped, 3 5/8-in. leg)	40	12,000	2,900	72.5
Slimline (96T12 425 mA)	75	12,000	6,300	84.0
Preheat (T17)	90	9,000	6,400	71.1
High output (96T12, 800 mA)	110	12,000	9,200	83.6
Grooved 'amp (96PG17, 1500 mA)	215	9,000	16,000	74.4
C. Fluorescent (other)				
Rapid start (T12, deluxe cool white)	40	20,000+	2,200	55.0
Rapid start (T12, white)	40	20,000+	3,200	80.0
Rapid start (T12, warm white)	40	20,000+	3,150	78.7
Rapid start (T12, deluxe warm white)	40	20,000+	2,150	53.7
Rapid start (T12, daylight)	40	20,000+	2,600	65.0

Table 16 (Continued)

Lamp	Lamp watts	Rated average life, hours	Approx. initial lumens	Approx. initial efficacy, lm/lamp W
Rapid start (T12, natural)	40	20,000+	2,100	52.5
Rapid start (T12, 5,000 K)	40	20,000+	2,200	55.0
Rapid start (T12, 7,500 K)	40	20,000+	2,000	50.0
Rapid start (T12, blue)	40	20,000+	1,160	29.0
Rapid start (T12, gold)	40	20,000+	2,400	60.0
Rapid start (T12, green)	40	20,000+	4,500	112.5
Rapid start (T12, pink)	40	20,000+	1,160	29.0
Rapid start (T12, red)	40	20,000+	200	5.0
D. High-intensity discharge (HID)				
1. Mercury vapor (E-37)				
Clear	400	24,000	21,000	52.5
Color improved	400	24,000	20,500	51.3
Deluxe white	400	24,000	22,500	56.3
Warm deluxe white	400	24,000	20,000	50.0
2. Mercury vapor (BT-56)				
Clear	1,000	24,000	57,000	57.4
Color improved	1,000	24,000	55,000	55.0
Deluxe white	1,000	24,000	63,000	63.0
Warm deluxe white	1,000	24,000	58,000	58.0
3. Metal halide				
E-37	400	10,000	34,000	85.0
BT-56	1.000	10,000	100,000	100.0
BT-56	1.500	1,500	155,000	103.3
4. High pressure sodium (Lucalox)				
	100	12,000	9,500	95.0
	150	12,000	16,000	106.7
	250	15,000	30,000	120.0
	400	20,000	50,000	125.0
	1,000	15,000	140,000	140.0
E. Electric arc				
High intensity	11,700	—	36,800	31.4

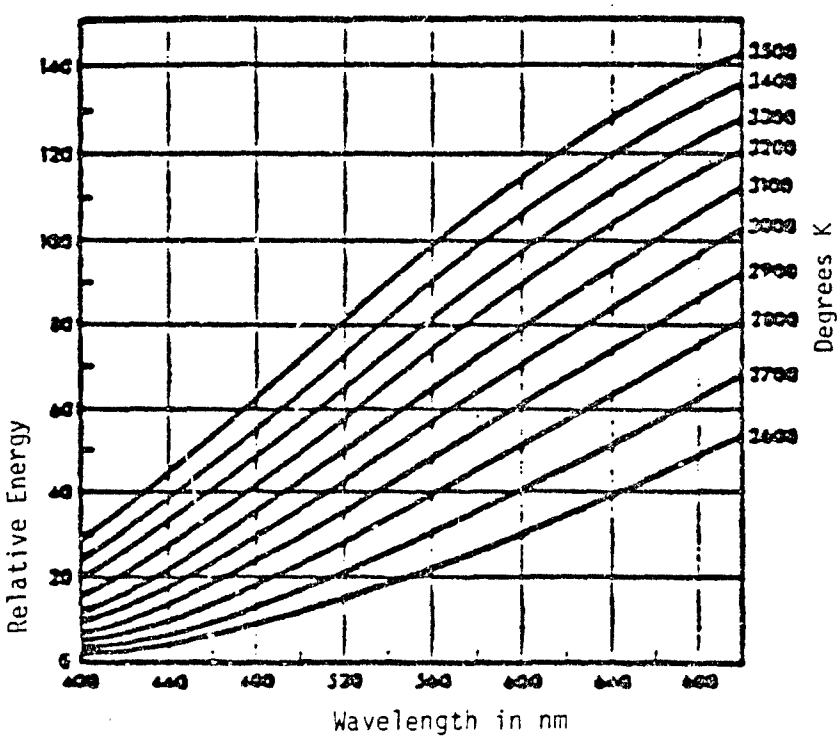


Figure 28. Spectral Power Distribution in the Visible Region from Tungsten Filaments of Equal Wattage but Different Temperatures.

Table 17

Reflectance of Various Materials for Energy Wavelengths in the Region of 253.7 nm (Reference 36)

Material	Reflectance (percent)
Aluminum	
Untreated surface	40-60
Treated surface	60-89
Sputtered on glass	75-85
Paints	55-75
Stainless steel	25-30
Tin plate	25-30
Magnesium oxide	75-88
Calcium carbonate	70-80
New plaster	55-60
White baked enamels	5-10
White oil paints	5-10
White water paints	10-35
Zinc oxide paints	4-5

Hangars typically have extensive metallic surfaces, both coated and uncoated, as well as all kinds of other surfaces, both permanent and temporary, which are all either specular, spread, diffuse, or compound reflectors of light. In some instances puddles of water or other liquids may be on the floor or immediately outside the hangar doors. They also can be either spectrally selective or non-selective in their reflectance. Figure 29 (Reference 37) shows the reflectance characteristics of materials of interest, particularly in the ultraviolet region. Table 18 (Reference 38) shows the reflectance and transmittance characteristics of some materials of interest, particularly in the infrared region.

Table 19 (Reference 39) shows the reflectances of a wide variety of materials.

C. Natural Phenomena

1. Sunlight

The color temperature of the sun as received at the outside of the earth's atmosphere is about 6500°K. The energy is received at an average rate of 1350 watts per square meter. About 75% of this energy is received at the earth's surface at sea level on a clear day at the equator. See Figure 30 (Reference 40). The illuminance at the earth's surface on a sunny day can exceed 10,000 footcandles, which on a cloudy day can drop to less than 1000 footcandles. Direct or reflected sunlight has the capability to trigger fire detectors unless they are made "solar blind."

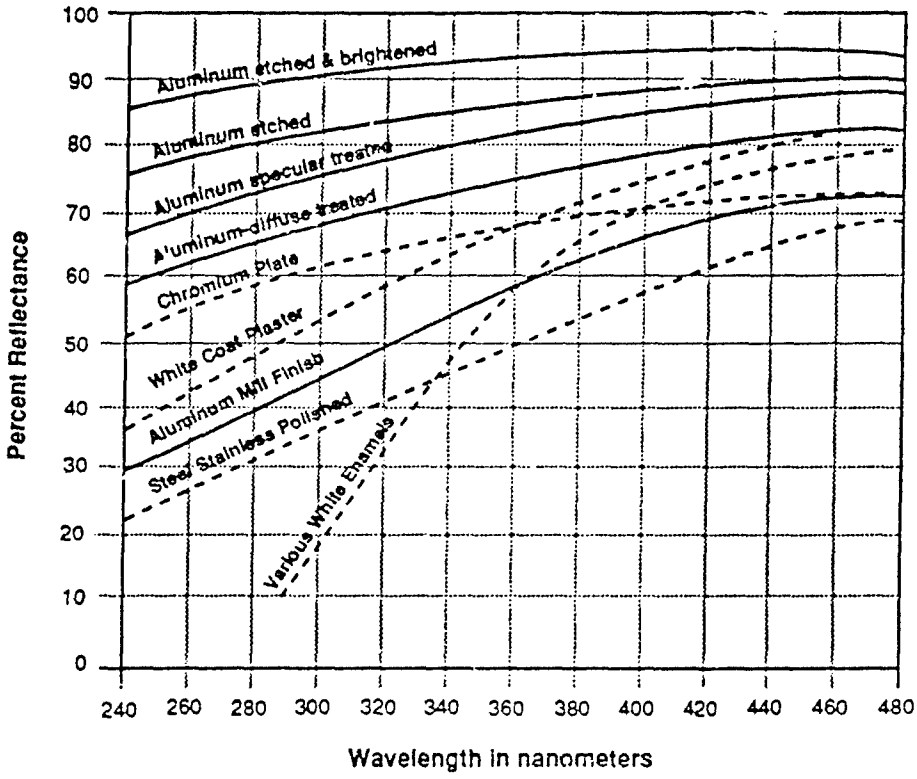


Figure 29. Spectral Reflectance Characteristics of Various Materials in the Blue, Violet, and UV Spectral Regions

Table 18

Reflectance (R) and Transmittance (T) Properties of Materials Used for Lighting In the Visible and Infrared Regions

Material	Visible Wavelengths						Near Infrared Wavelengths						Far Infrared Wavelengths							
	400 nm		500 nm		600 nm		1000 nm		2000 nm		4000 nm		7000 nm		10,000 nm		12,000 nm		15,000 nm	
	R	T	R	T	R	T	R	T	R	T	R	T	R	T	R	T	R	T	R	T
Specular aluminum	87	0	82	0	86	0	97	0	94	0	88	0	84	0	27	0	16	0	14	0
Diffuse Aluminum	79	0	75	0	84	0	86	0	95	0	88	0	81	0	68	0	49	0	44	0
White synthetic enamel	48	0	85	0	84	0	90	0	45	0	8	0	4	0	4	0	2	0	9	0
White porcelain enamel	65	0	84	0	83	0	76	0	38	0	4	0	2	0	22	0	8	0	9	0
Clear glass-3.2 millimeters (.125 inch)	8	91	8	92	7	92	5	92	23	90	2	0	0	0	24	0	6	0	5	0
Opal glass-3.9 millimeters (.155 inch)	28	36	26	39	24	42	12	59	16	71	2	0	0	0	24	0	6	0	5	0
Clear acrylic-3.1 millimeters (.120 inch)	7	92	7	92	7	92	4	90	8	53	3	0	2	0	2	0	3	0	3	0
Clear polystyrene-3.1 millimeters (1.20 inch)	9	87	9	89	8	90	6	90	11	61	4	0	4	0	4	0	4	0	5	0
White acrylic-3.2 millimeters (.125 inch)	18	15	34	32	30	34	13	59	6	40	2	0	3	0	3	0	3	0	3	0
White polystyrene-3.1 millimeters (.120 inch)	26	18	32	29	30	30	22	48	9	35	3	0	3	0	3	0	3	0	4	0
White vinyl-0.75 millimeters (.030 inch)	8	72	8	78	8	76	6	85	17	75	3	0	2	0	3	0	3	0	3	0

Note: (a) Measurements in visible range made with General Electric Recording Spectrophotometer. Reflectance with black velvet backing for samples. (b) Measurements at 1000 nm and 2000 nm made with Beckman DK2-R Spectrophotometer. (c) Measurements at the wavelengths greater than 2000 nm made with Perkin-Elmer Spectrophotometer. (d) Reflectances in infrared relative to evaporative aluminum on glass.

Table 19

Material	Reflectance* or Transmittance† (per cent)	Characteristics
		Reflecting
Specular		
Mirrored and optical coated glass	80 to 99	Provide directional control of light and brightness at specific viewing angles. Effective as efficient reflectors and for special decorative lighting effects.
Metalized and optical coated plastic	75 to 97	
Processed anodized and optical coated aluminum	75 to 95	
Polished aluminum	60 to 70	
Chromium	60 to 65	
Stainless steel	55 to 65	
Black structural glass	5	
Spread		
Processed aluminum (diffuse)	70 to 80	General diffused reflection with a high specular surface reflection of from 5 to 10 per cent of the light.
Etched aluminum	70 to 85	
Satin chromium	50 to 55	
Brushed aluminum	55 to 58	
Aluminum paint	60 to 70	
Diffuse		
White plaster	90 to 92	Diffused reflection results in uniform surface brightness at all viewing angles. Materials of this type are good reflecting backgrounds for coves and luminous forms.
White paint**	75 to 90	
Porcelain enamel**	65 to 90	
White terra-cotta**	65 to 80	
White structural glass	75 to 80	
Limestone	35 to 65	
		Transmitting
Glass††		
Clear and optical coated	80 to 99	Low absorption; no diffusion; high concentrated transmission. Used as protective cover plates for concealed light sources
Configursted, obscure, etched, ground, sandblasted, and frosted	70 to 85	Low absorption; high transmission; poor diffusion. Used only when backed by good diffusing glass or when light sources are placed at edges of panel to light the background.
Opalescent and alabaster	55 to 80	Lower transmission than above glasses; fair diffusion. Used for favorable appearance when indirectly lighted.
Flashed (cased) opal	30 to 65	Low absorption; excellent diffusion. Used for panels of uniform brightness with good efficiency.
Solid opal glass	15 to 40	Higher absorption than flashed opal glass; excellent diffusion. Used in place of flashed opal where a white appearance is required.
Plastics		
Clear prismatic lens	70 to 92	Low absorption; no diffusion; high concentrated transmission. Used as shielding for fluorescent luminaires, outdoor signs and luminaires.
White	30 to 70	High absorption; excellent diffusion. Used to diffuse lamp images and provide even appearance in fluorescent luminaires.
Colors	0 to 90	Available in any color for special color rendering lighting requirements or esthetic reasons.
Marble (impregnated)	5 to 30	High absorption; excellent diffusion; used for panels of low brightness. Seldom used in producing general illumination because of the low efficiency
Alabaster	20 to 50	High absorption, good diffusion Used for favorable appearance when directly lighted.

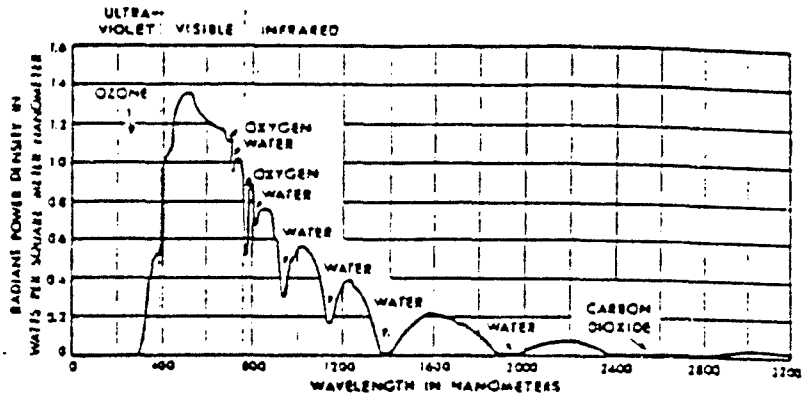
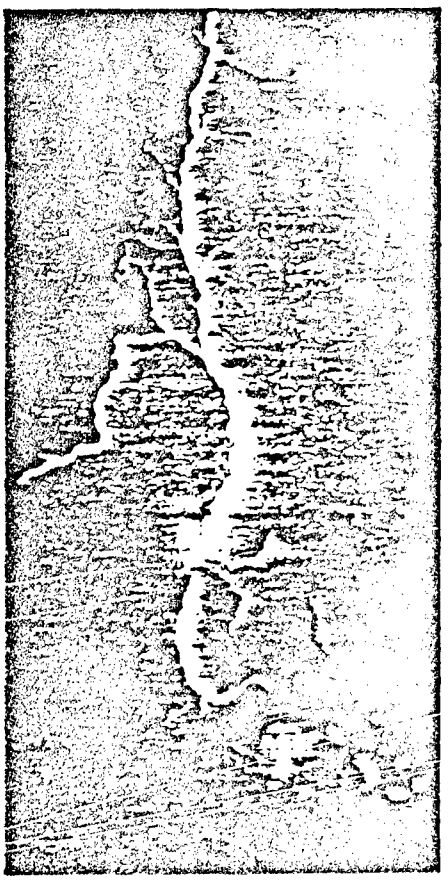


Figure 30. Spectral Distribution of Solar Radiant Power Density at Sea Level Showing Ozone, Oxygen, Water and Carbon Dioxide Absorption Bands.



(a) Example of Lightning Flashes over Cerro Negro Volcano

(b) Lightning Flashes During Summer Storm

Figure 31. Luminous Features of Typical Lightning Flashes

2. Lightning

As a meteorological phenomenon arising from the accumulation of tremendous electrical charges, usually positive, in the formation of clouds, these charges are suddenly released to the ground in a spark type discharge through the atmosphere. Spectrally, the discharge corresponds to that of an ordinary spark in air, which consists principally of nitrogen bands, though sometimes hydrogen lines appear, due to dissociation of water vapor. Whatever is in the atmosphere locally likewise is excited thereby into emission. See Figure 31 (References 41 and 42).

When the electrical potential between two clouds or between a cloud and the earth reaches a sufficiently high value, about 10,000 volts per cm or about 25,000 volts per inch, the air becomes ionized along narrow path and a lighting flash results. Most lightning flashes are multiple events, consisting of as many as 42 main "strokes," each of which is preceded by a "leader" stroke. The average interval between successive lightning strokes is 0.02 seconds, and the average flash lasts 0.25 seconds. Because the duration of one powerful stroke is no more than 0.0002 seconds, the intervals between strokes account for most of the duration of a lightning flash.

D. ELECTRICAL DISCHARGE

The arcing of power transformers, motors and any other electrical devices produces a spark or sparking in air which has the same spectral effect as lightning. Whatever is in the air locally, as well as whatever materials are involved in the source and grounding of the spark, will determine the spectral content of the spark discharge. Like lightning, the principal emissions are of nitrogen bands; sometimes hydrogen lines, and that of the other materials involved.

Flashlamps spectrally are as described under "Lights" above. The Norman family of flashlamps feature xenon gas-filled flashlamps, which therefore have a spectral output characteristic of xenon lamps. The energy output of the three Norman flashlamps measured at Edwards AFB, as summarized in Table 2, is as follows:

Norman 200B:	200 watt-seconds
Norman P500:	500 watt-seconds
Norman 2000B:	2000 watt-seconds

The other flashlamps in Table 2 have energy cutputs as follows:

Metz 60CT-4	160 watt-seconds, variable
Vivitar 285HB:	125 watt-seconds

Carbon arcs are of three types: (1) low intensity, (2) high intensity, and (3) flame arcs.

The low intensity arc, when operated at radiation standard conditions, corresponds to a blackbody at 3800°K. The luminance can be varied from 150 to 180 candelas per square centimeter, and likewise the color temperature from 3600 to 3800°K, exceeding those from incandescent tungsten. See Figure 32 (Reference 43) for spectral outputs.

The high intensity arcs range in input power from 2 to 30 kilowatts, in crater luminous intensity from 10,500 to 185,000 candelas, and in crater luminance from 55,000 to 145,000 candelas per square centimeter. The color temperature varies from 2900°K to as high as 6500°K, corresponding to the sun's color temperature. These values are modified by the characteristics of the optical system used with them. One notable example of a carbon arc searchlight emits an intensity of 68,000 candelas, a crater luminance of 65,000 candelas per square centimeter, and has a color temperature of 5400°K. See Table 20 (Reference 44) for various direct current carbon arc applications.

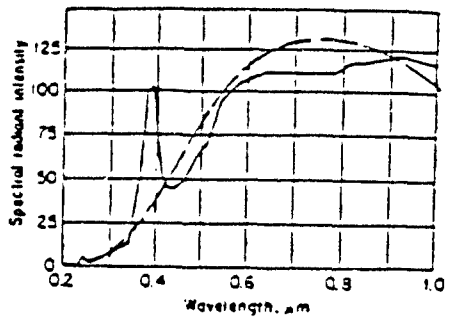
Flame arcs have power inputs ranging from 1 to 4 kilowatts, and show the effect of different currents, voltages and flame materials. The wavelength intervals are chosen to coincide with the needs of various applications. Figure 33 (Reference 45) shows the spectral power distribution of flame arcs used for graphic arts.

Table 21 (Reference 46) shows the wide variety of effects achieved with the use of flame additives.

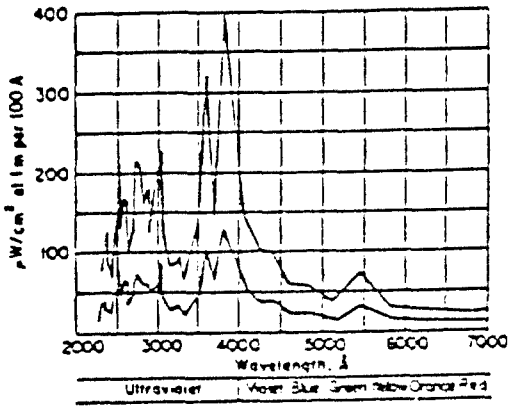
E. NON-DESTRUCTIVE INVESTIGATIVE DEVICES

The principal instrument used for non-destructive investigative purposes is the X-ray machine. Since its electrical operation requires very high voltages and currents to produce the particular x-ray energies required, whether in a pulsed or steady mode, the concomitant requirements for shielding against stray and/or reflected radiation, as well as proper shielding and grounding of all electrical parts of the system, are of utmost importance. Besides the capability to produce secondary radiation in the ultraviolet region, along with the x-ray radiation itself, which can penetrate and ionize gas-filled UV fire detectors, it is also possible to generate EMI/RFI radiation which can affect the circuitry of the detector system either through the power cables or by pickup in some other way.

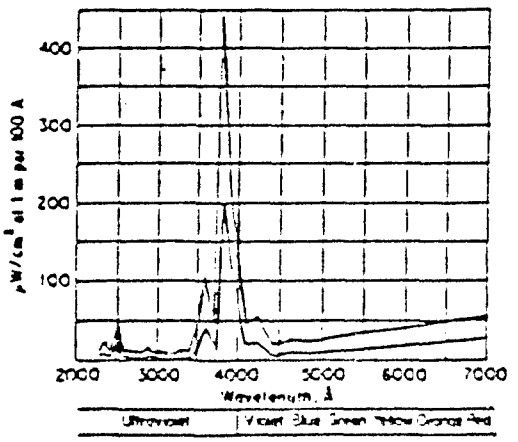
Such machines generate hard x-ray energies from 160 to 300 Kev, with wavelengths from 0.385 to 0.205 Angstroms. Their capability to reflect from and penetrate metals over the thickness ranges and materials of interest provide an investigative tool sometimes necessary to use on an aircraft in a hangar. This demands that proper precautions be taken to avoid triggering a false alarm.



(a) Spectral Distribution of Radiant Flux from 30-A, 55-V dc Low Intensity Arc with 12-mm Positive Carbon (Solid Line) and of a 3800° K Blackbody Radiator (Broken Line).



(b) Spectral Energy Distribution of Carbon Arc with Core of Soft Carbon: Upper Curve; 60-A ac, 50-V Across the Arc; Lower Curve: 30-A ac, 50-V Across the Arc.



(c) Spectral Energy Distribution of Carbon Arc with Polymetallic-Cored Carbons: Upper Curve: 60-A ac, 50-V Across Arc; Lower Curve: 30-A ac, 50-V Across Arc.

Figure 32. Examples of Spectral Energy Distribution of Various Carbon Arcs.

TABLE 20

Direct-Current Carbon Arc

	Low Intensity	Non-Rotating High Intensity				Rotating High Intensity		
	Application Number*							
	1	2	3	4	5	6	7	8
Type of Carbon	Microscope	Projector	Projector	Projector	Projector	Projector ***	Searchlight	Studio "Yellow Flame"
Positive Carbon								
Diameter, millimeters (inches)	5	7	8	10	11	13.6	16	16
Length, millimeters (inches)	200(8)	300-355(12-14)	300-355(12-14)	500(20)	500(20)	318(12.5)	560(22)	560(22)
Negative Carbon								
Diameter, millimeters (inches)	6	6	7	9(11/32)	10(3/8)	13(1/2)	11	13.5(17/32)
Length, millimeters (inches)	114(4 1/2)	230(9)	230(9)	230(9)	230(9)	230(9)	300(12)	230(9)
Arc current, amperes	5	50	70	105	120	160	150	225
Arc volts, dc	59	40	42	59	57	66	78	70
Arc power, watts	295	2000	2940	6200	6840	10600	11700	15800
Burning rate, millimeters (inches) per hour								
Positive carbon	114(4.5)	295(11.6)	345(13.6)	546(21.5)	419(16.5)	432(17.0)	226(8.9)	513(20.2)
Negative carbon	53(2.1)	109(4.3)	109(4.3)	74(2.9)	61(2.4)	56(2.2)	99(3.9)	56(2.2)
Approximate crater diameter, millimeters (inches)	3(0.12)	6(0.23)	7(0.28)	9(.36)	10(0.39)	13(0.50)	14(0.55)	15(0.59)
Maximum luminance of crater, candelas per square centimeter	15000	55000	83000	90000	35000	96000	65000	68000
Forward Crater candlepower, candelas	975	10500	22000	36000	44000	63000	68000	99000
Crater lumens**	3100	36800	77000	126000	154000	221000	250000	347000
Total lumens†	3100	55000	115000	189000	231000	368000	374000	521000
Total lumens per Arc Watt	10.4	29.7	39.1	30.5	33.8	34.7	32.0	33.0
Color temperature, kelvins‡	3600	5950	5500-6500	5500-6500	5500-6500	5500-6500	5400	4100

*Typical applications: 1, microscope illumination and projection; 2,3,4,5, and 6, motion picture projection; 7, search projection; 8, motion picture set lighting and motion picture and television background projection.

**Includes light radiated in forward hemisphere.

†Includes light from crater and arc flame in forward hemishpere.

‡Crater radiation only.

***Jointed carbon.

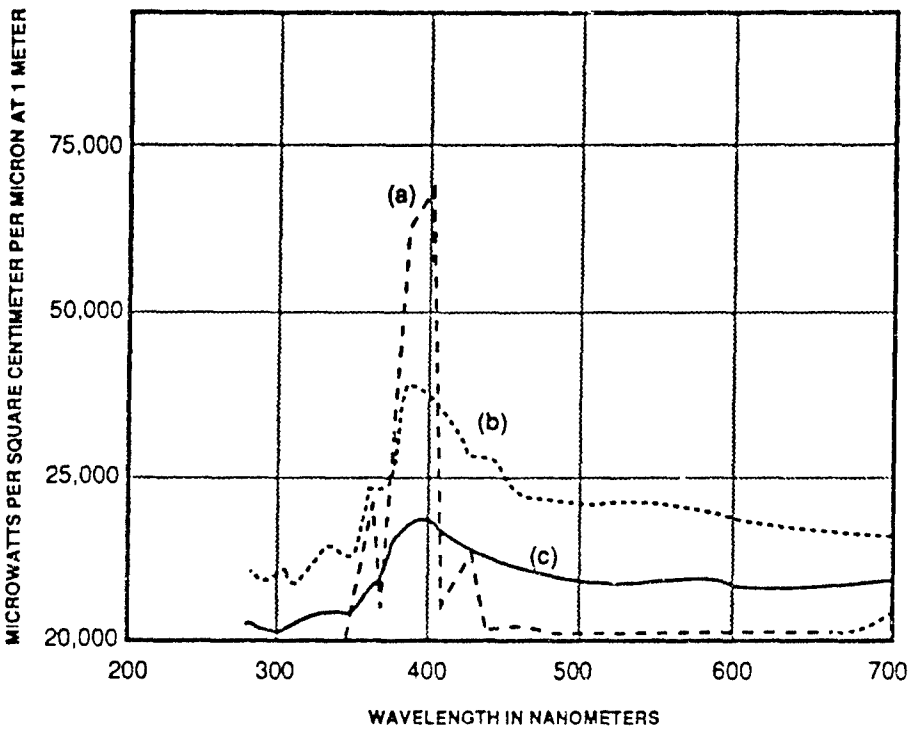


Figure 33. Spectral Power Distribution of Arcs Used for Graphic Arts. (a) Half-inch enclosed arc carbons, 16 amperes, 138 volts. (b) Nine millimeter high density photo carbons, 95 amperes, 30 volts. (c) Half-inch photographic white flame carbons, 38 amperes, 50 volts.

Table 21

Flame-Type Carbon Arcs

	Application Number[a]				
	1	2	3	4	5[c,e]
Type of Carbons	"Sunshine"	"Sunshine"	Enclosed arc	Photo[b]	Photo[c]
Flame Materials	Rare earth	Rare earth	None	Rare earth	Rare earth
Burning Position[d]	Vertical	Vertical	Vertical	Vertical	Horizontal
Upper carbon[e]					
Diameter, millimeters (inches)	22(7/8)	22(7/8)	13(1/2)	13(1/2)	9(3/8)
Length, millimeters (inches)	300(12)	300(12)	75 to 400 (3 to 16)	300(12)	200(8)
Lower carbon[e]					
Diameter, millimeters (inches)	13(1/2)	13(1/2)	13(1/2)	13(1/2)	9(3/8)
Length, millimeters (inches)	300(12)	300(12)	75 to 400 (3 to 16)	300(12)	200(8)
Arc current, amperes	60	80	16	38	95
Arc voltage, ac[f]	50	50	138	50	30
Arc power, kilowatts	3.0	4.0	2.2	1.9	2.85
Candlepower[g] (candelas)	9100	10000	1170	6700	14200
Lumens	100000	110000	13000	74000	156000
Lumens per arc watt	33.33	27.5	5.9	39.8	54.8
Color temperature, kelvins	12800[h]	24000[h]	[h]	7420[h]	8150
Spectral intensity (microwatts per square centimeter one meter from arc axis[i])					
Below 270 nm	102	140	--	95	--
270-320 nm	186	244	--	76	100
320-400 nm	2046	2816	1700	684	1590
400-450 nm	1704	2306	177	722	844
450-700 nm	3210	3520	442	2223	3671
700-1125 nm	3032	3500	1681	1264	5632
Above 1125 nm	9820	11420	6600	5189	8763
Total	20100	24000	10600	10253	20600
Spectral radiation (per cent of input power)					
Below 270 nm	.34	.35	--	.5	--
270-320 nm	.62	.61	--	.4	.35
320-400 nm	6.82	7.04	7.7	3.6	5.59
400-450 nm	5.68	5.90	.8	3.8	2.96
450-700 nm	10.70	8.80	2.0	11.7	12.86
700-1125 nm	10.10	8.75	7.6	6.7	19.75
Above 1125 nm	32.70	28.55	29.9	27.3	30.69
Total	67.00	60.00	48.0	54.0	72.20

[a]Typical applications: 1 and 2, accelerated exposure testing, or accelerated plant growth; 3,4, and 5 blueprinting, diazo printing, photo copying, and graphic arts.

[b]Photographic white flame carbons.

[c]High intensity photo 98 carbons.

[d]All combinations shown are operated coaxially.

[e]Both carbons are same in horizontal, coaxial ac arcs.

[f]All operated on alternating current.

[g]Horizontal candlepower, transverse to arc axis.

[h]Deviate enough from blackbody colors to make color temperature of doubtful meaning.

[i]See 1981 Application Volume, Section 11 Fig. 11-18 for spectral power distribution curve.

F. ELECTROMAGNETIC WAVES

The sources of radiation that can cause false alarms can emanate from:

(1) communication systems
(2) attack radars
(3) terrain-following radars
(4) weapons systems
(5) electronic countermeasure jammers
(6) other aircraft and hangar equipment generating electromagnetic emissions

Although not the same as x-rays for penetrating through shielding materials, the capability to induce effects in the electronics of fire detection systems can trigger a false alarm. Such induced effects may enter well-shielded circuitry through some component in a position to effectively function as an antenna into an enclosure, or enter by way of the power line. Until it happens, it is difficult to predict such an effect, or even protect against it fully. It is one effect to consider when all other possible effects have been ruled out as the cause of a false alarm.

G. AIRCRAFT ENGINE EMISSIONS

UV and IR emissions from aircraft engines during start-up and from power levels through the afterburner mode, have been associated with several reported false alarm events. However, unless the detector is in a position to "look" down the throat of the engine, there is doubtfully any UV in the engine effluent exhaust. At power levels, however, of 80 percent and greater, and certainly with the afterburner on, UV radiation is present.

One source reports that during start-up through reheat:

1. Infrared Measurement: at 4.38 μm center wavelength, with a bandwidth of 0.7 μm, and at a distance of 10 meters (32.8 feet):
   (1) peak irradiance = 500 $\mu W/cm^2$
   (2) average irradiance = 100 $\mu W/cm^2$.

This is similar to a 1 square foot JP-4 fuel panfire at 15 meters (49.2 feet):

(1) irradiance $\cong$ 100 $\mu W/cm^2$;

and to a 4 square foot JP-4 fuel panfire likewise at 15 meters:

(2) irradiance $\cong$ 500 $\mu W/cm^2$.

2. Ultraviolet Measurements: an avalanche counter detector in the 190 to 260 nm UV band, at a distance of 10 meters (32.8 feet), looking 90 degrees tc the engine exhaust flow indicated:

(1) engine start up: no counts
(2) engine idle: no counts
(3) engine increase to 80% operation: no counts
(4) engine during reheat: very high counts

This response is similar to that of a 2'x 2' JP-4 fuel panfire at 6 meters (19.7 feet).

These levels of UV and IR output during reheat, but not during the other periods of engine operation, are adequate to emulate a JP-4 fire. If the exhaust, however, impinges on the face of the detector, or near it, there is sufficient heat to affect the IR channel.

H. PERSONNEL ITEMS

Several personnel items emit radiation either in the UV or IR bands, or both, that may affect fire detectors. These are:

(1) lighted cigarettes, cigars
(2) matches
(3) butane lighters

These items produce enough UV and IR to set off a fire detector at a distance of about 10 feet. The levels of irradiance are to be determined.

I. TOOLS/OPERATIONS

This category primarily includes all welding operations. The data summarized in Table 2, measured in the Welding Laboratory at Edwards AFB, provide the levels of irradiance to be encountered in such operations.

It is apparent that UV levels of irradiance all could have triggered the UV fire detectors. At least in some if not all cases the IR levels could trigger the IR detectors. The IR levels need further verification.

J. HOT BODIES, BLACKBODY RADIATORS

The discussion above under the incandescent lamps category addresses blackbody radiation that has direct application here as well.

The investigation of the AGE equipment at Edwards AFB as summarized in the data in Table 2 gives the levels of radiance emitted by such bodies that are hot in certain areas during operation, and are located in positions that, either by direct or reflected radiation, potentially could trigger false alarms.

Where the measurements at Edwards AFB give the results as measured at particular distances, consideration is given here to the fact that welding operations reach temperatures far in excess of those measured remotely, since the melting points of the metals involved are much higher. These theoretical values provide an interesting comparison with the field measured values. The theoretical results are given in Table 22. These should be compared with Table 2.

Other heating sources, such as thermal treating blankets and electrical or kerosene fueled heaters likewise provide substantial radiances.

When consideration is given to the simultaneous operation of various combinations of the multiplicity of possible false alarm sources, all emitting direct and/or reflected UV visible and IR radiation, a very complex hangar scenario emerges. It is no wonder that fire detectors, with triggering thresholds already on the thin edge of being ready to fire, can be pushed over the edge to triggering by some seemingly inconsequential and minuscule addition of radiation from something somewhere. It seems that the entire hangar scenario needs to be modeled, evaluated in detail, and when conclusions are reached, be vigorously controlled as to what can and cannot be built into the hangar to start with, and thereafter what can or cannot be used in it. It is obvious from the number of false alarms that still occur, that, even though much of this already has been done, it is not enough. Much that still occurs is by the chance combination of sources rather than from design. It appears that design must address the entire problem more broadly and deeply.

K. SECURITY PERSONNEL WEAPONS

As described in the preceding section, it may take only some small increment of radiation from some seemingly minuscule source somewhere to push the fire detectors over the already nearly satisfied threshold into a false alarm. The firing of any weapon can be such a source. Since the gunpowder on explosion gives a very high peak intensity, very short duration pulse of radiation in the UV, visible and IR bands of radiation, it appears that the best characteristic to use to achieve immunity to such events is to exploit pulse width discrimination against them. Besides proper knowledge of the spectral energy distribution of such a pulse being desirable, the more practical characteristic to use is the pulse duration of each firing cubicle can be applied more simply in fire detector circuitry. Hence, this needs to be determined for all the candidate security personnel weapons, namely:

M-16 rifle	38-caliber pistol
M-60 machine gun	12-gauge shotgun
M-79 grenade launcher	

Table 22

Melting Points, Radiances and Irradiances of Metals Welded with Welding Rods

	Melting Point °F	Melting Point °K	Emissivity	4.3μm Radiant Exitance μw/cm²μm	4.3μm Irradiance μw/cm²μm
		TIG Welds (x=4.5 ft.)			
I. Aluminum 6061	1218	932	0.2-0.4	7.22E5	2.30E5
4043 Rod	1218	932			
II. Magnesium	1202	923	0.03-0.15	6.97E5	2.22E5
A Z 31 B Rod	1202	923			
III. Titanium	3500	2200	0.5-0.7	7.12E6	2.27E6
Titanium Filler Rod	3500	2200			
IV. Stainless Steel 410	2760	1789	0.1-0.2	4.64E6	1.48E6
410 Rod	2760	1789			
V. Carbon Steel	2500	1644	0.1-0.2	3.82E6	1.22E6
Carbon Steel Rod	2500	1644			
		Arc Welds (x=7 ft.)			
I. Steel Plate	2550	1672	0.1-0.2	3.98E6	1.27E6
6013 Rod	2500	1644			
II. Carbon Steel	2500	1644	0.1-0.2	3.82E6	1.32E6
6013 Rod	2500	1644			
III. Stainless Steel	2760	1789	0.1-0.2	4.64E6	1.48E6
312-16 Stainless Steel Rod	2700	1755			
IV. Nickel	2650	1728	0.3-0.6	4.44E6	1.41E6
Nickel 141 Rod	2650	1728			
V. Aluminum	1210	928	0.2-0.4	7.11E5	2.26E5
Eutectic Super 2109 Rod	2100	1422			
				2.67E6	8.51E6
		MIG Welds (x=7 ft)			
I. Aluminum 4043	1218	932	0.2-0.4	7.22E5	2.30E5
ER 70S-6 Wire	2730	1772			
II. Mild Steel	2730	1772	0.1-0.2	4.54E6	1.45E6
ER 70S-6 Wire	2730	1772			
		Oxyacetylene Cut and Weld (x=7 ft.)			
I. Cutting: Mild Steel	2730	1772	0.1-0.2	4.54E6	1.45E6
II. Welding: Mild Steel	2730	1772	0.1-0.2	4.54E6	1.45E6
Mild Steel Rod	2730	1772			

The flash-pulse characteristics can be readily determined with a fast-responding photodetector and scope. These measurements were not part of this program and need to be carried out on a military firing range during both daytime and nighttime conditions.

L. CONCLUSION

As a final summary of sources of light in terms of their luminances and therefore their output in the visible region of the spectrum expressed in photometric units, many of the sources discussed throughout this document are tabulated with their approximate average luminances in candela/square meter in Table 23 (Reference 47). To this point, most light outputs have been given in radiometric units, since the primary objective is to determine their UV and IR values for direct comparison.

Table 23
Approx[illegible]e Luminance Of Variou[illegible]Light Sources

Compiled by C.J. Allen and G.D. Rowe

Source		Approx. avg luminance* (Cd cm^{-2})
Natural Sources		
Clear Sky	Average luminance	0.8
Sun (as observed from earth's surface)	At median	160000
Sun (as observed from earth's surface)	Near horizon	600
Moon (as observed from earth's surface)	Bright spot	0.25
Combustion Sources		
Candle flame (sperm)	Bright spot	1.0
Welsback mantle	Bright spot	6.2
Acetylene flame	Mees burner	10.5
Photoflash lamps		16000-40000 peak
Incandescent electric lamps	3 Lumens per watt	52
Carbon filament	Vacuum lamp-10 lumens per watt	200
Tungsten filament	Gas filled lamp-20 lumens per watt	
Tungsten filament	750-watt projection lamp-25 lumens per watt	7500
Fluorescent lamps (cool white)		
Rapid start (40wT12)	430 mA	0.82
High-output (96T12)	800 mA	1.13
Grooved bulb (96T17)	1500 mA	1.50
Fluorescent lamps (other than cool white)		
Daylight (40wT12)	430 mA	0.62
Blue (40wT12)	430 mA	0.30
Green (40wT12)	430 mA	1.17
Red (40wT12)	430 mA	0.05
High-intensity discharge (HID)		
Mercury-vapor (E-37)		
Clear	400 watt	970
Color-improved	400 watt	11.0
Deluxe-white	400 watt	12.1
Mercury-vapor (BT-56)		
Clear	1000 watt	980
Color-improved	1000 watt	15.0
Deluxe-white	1000 watt	17.2

Table 23 (Continued)

Source		Approx. avg luminance* (Cd cm^{-2})
Metal Halide (E-37)		
Clear	400 watt	810
Color-improved	1000 watt	930
Deluxe white	1500 watt	1620
High pressure sodium		
(Lucalox)	250 watt	520
	400 watt	780
	1000 watt	810

* Luminance values perpendicular to lamp axis

SECTION VI

LABORATORY MEASUREMENTS OF POTENTIAL FALSE ALARM SOURCES

A. INTRODUCTION

Besides the data summarized from field measurements and other sources, a set of radiation sources were studied in the laboratory with the same set of instruments used in the field. This proved successful in generating corroborative data.

This in turn became the basis for generating a set of curves which enable prediction of the likelihood of each radiation source being able to trigger a false alarm as a function of distance in UV and IR optical fire detectors. Preliminary checkout of this concept with a set of commonly used optical fire detectors is proving successful, as will be described below. Such curves could be of considerable value to fire detector designers in their effort to design devices universally immune to false alarms.

As will be seen, the concept provides useful information not only for an individual source regarding its capability to trigger a false alarm alone, but how several sources in combination, even though individually not capable of triggering a false alarm beyond a particular distance, can combine additively with otherwise weak irradiances at these greater distances to cause a false alarm. With these curves such estimations can be made.

The particular radiation sources studied are given first. Next, the resulting measurement data are summarized in detail in a table. This data is then used to compute the irradiances of each source as a function of distance. The data and curves are then given and discussed, along with some examples of applications and testing for validity of the concept.

From physics, if the measurement data are correct, it is then to be expected that the concept would prove valid. The preliminary indication is that it does prove valid. This can open the door to several new ways to help achieve immunity of fire detectors to certain false alarm sources, but it needs further study.

B. RADIATION SOURCES STUDIED

Among the many types and varieties of potential false alarm sources studied in this program, several were subjected to laboratory measurements and tests. The particular radiation sources studied in the laboratory are listed in Table 24. Figures 34 through 36 are photographs of these sources.

Table 24

Radiation Sources Studied in the Laboratory

	ITEM	MODEL	WATTAGE
1.	Metal Halide Lamp	MVR 1000/U	1000 Watts
2.	Mercury Vapor Lamp	H33HL-400/DX	400 Watts
3.	High Pressure Sodium Lamp	Lucalox, LU1000	1000 Watts
4.	Metal Halide Lamp	MH 250/U	250 Watts
5.	Metal Halide Lamp	MVR 1500/HBU/E	1500 Watts
6.	Low Pressure Sodium Lamp	SOX35W, L70RB-35	35 Watts
7.	Mercury Vapor Lamp	H39KB-175	175 Watts
8.	F-16 Landing Light	GE4581	450 Watts
9.	F-16 Refueling Light	4028-1	15.4 Watts
10.	Aircraft Parking Lamp	1829	3.92 Watts
11.	Quartz Tungsten Halogen Lamp	T-3	300 Watts
12.	Truck Headlamp	GE4811 (43 Watts low beam;	53 W High
13.	Yellow Strobe Lamp	Tandy 49-527	2.4 Watts
14.	Red Flashing Warning Lamp	Tandy 42-3040	40 Watts
15.	Ultraviolet Black Light	FEIT Electric 75A/BL	75 Watts
16.	Soft White Incandescent	GE	150 Watts
17.	Clear Incandescent Lamp	GE	150 Watts
18.	Dual Fluorescent Lamps	Sylvania F40	69 Watts
19.	Electric Hot Plate	Hamilton Beach 813-4	75 Watts
20.	Electric Hot Plate	Eastern Electric	1000 Watts
21.	UV Insect Light	Electrocutter BK-50	-
22.	Flashlight with IR Lens		
23.	Infrared Heat Lamp		250 Watts

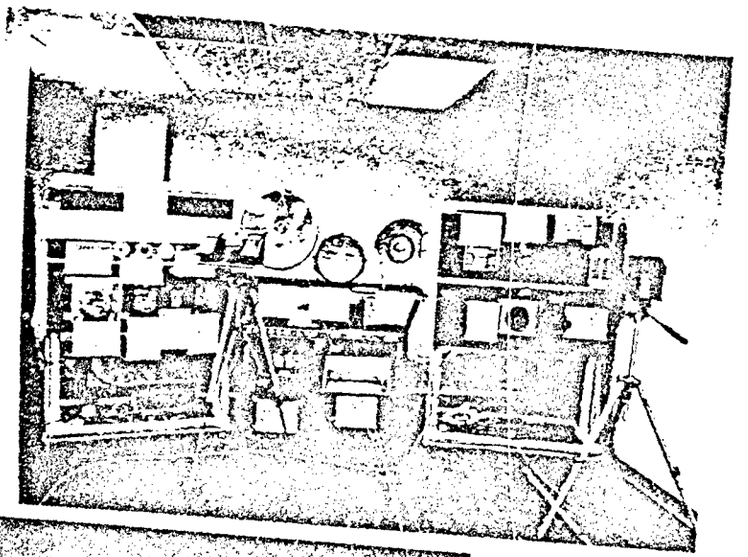


Figure 34. Lights and hot bodies used in lab measurements.

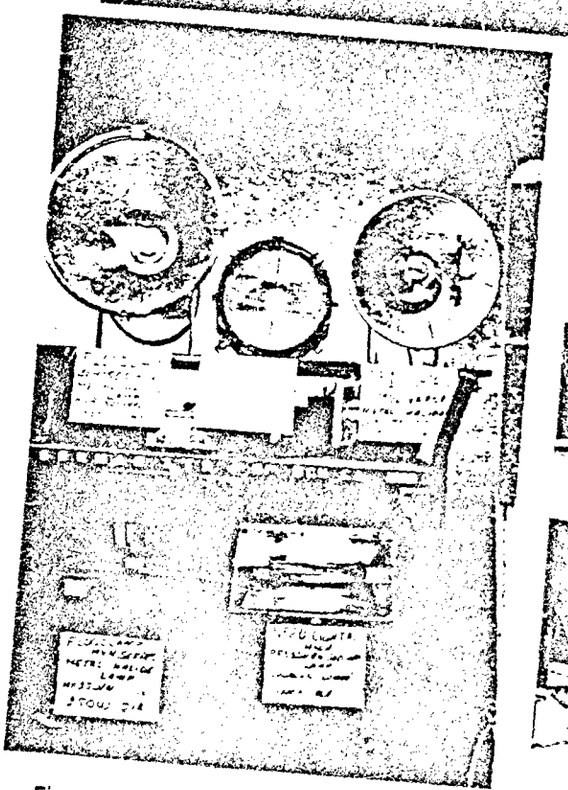


Figure 35. HID lamps used in lab tests

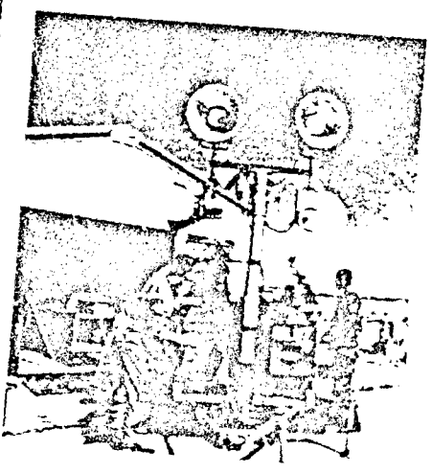


Figure 36. Typical TF-1 Lightall Lamps

C. MEASUREMENT DATA

The method of making the exitance measurements of each source is based on the requirement that the field-of-view (FOV) of each instrument must be filled by the radiation source. This dictated that the distance each instrument had to be from the source could be any distance up to the value that this ceased to be true.

From physics, all other parameters remaining constant, if the FOV remains filled as the distance is increased, even though the irradiance falls off inversely as the square of the distance, the area of the radiation source within the FOV conversely increases directly as the square of the distance, canceling the effect of the inverse square law falloff. Hence, as long as their FOV remains filled, the exitance value will not change as the distance is varied within the permissible range.

Review of the measurement data is given in Table 25. Table 25 shows that each instrument has the distance of the measurement given below each recorded exitance value. Since, however, the five Spectronics sensors, in the bands 254 nm, 300 nm, 365 nm, 405 nm, and 450 nm, respectively, are mounted on the same fixture, their distance is given only once in the 254 nm column.

1. Computed Irradiances and Curves

Because atmospheric transmittance, however, can be changing considerably in the UV and IR bands of interest, this is one parameter that does not remain constant as a function of distance, requiring appropriate correction. Therefore, in generating the data for the curves given below, both the inverse square law and the Lambert-Beer-Bouguer law are applied simultaneously to the measured values to derive the corrected values for the curves. Since, as will be seen in the curves, the most drastic falloff occurs over the range close to each source, it is important that appropriate correction be made over the distance of the measured and computed exitance values.

Table 26 gives a detailed listing of such computed values of irradiance for each radiation source as a function of distance. The basic starting value for each source and each curve is taken from the measured data of Table 25. The data in Table 26 is then used to plot the family of curves in Figures 37-43.

As is seen, the data is for two UV bands and one IR band. Since the UV fire detectors possibly respond to the burning JP-4 irradiances in the 200 nm and 254 nm bands, both bands are studied here. The IR band at 4.4 micrometers likewise is a well known feature of burning hydrocarbon fuels, being specifically considered at 4.37 micrometers because of good atmospheric transmittance data being available in this region.

Table 25
Laboratory Measurements

Group I: Exitances of High Intensity Discharge Lamps

ULTRAVIOLET				VISIBLE		INFRARED		FIRE DETECTORS-SINGLE		
200 nm $\mu W/cm^2$	254 nm $\mu W/cm^2$	300 nm $\mu W/cm^2$	365 nm $\mu W/cm^2$	405 nm $\mu W/cm^2$	450 nm $\mu W/cm^2$	4.37 μm $\mu W/cm^2$	TEMP. °K	SPECIAL UV FIRE DET.	SPECIAL IR FIRE DET.	ALL OTHER FIRE DET.
1. METAL HALIDE LAMP					MVR 1500/HBU/E			1500 WATTS		HANGARS
5.56E-2 (22") 5.16E-2 (8 FT.)	860 (12")	220 (12")	5680 (12")	10,450 (12")	5970 (12")	1.93E4 (21")	463.6	N	N	G RESPONDED ONCE AT 21", ALL OTHERS N
2. MERCURY VAPOR LAMP					H33GL-400/DX			400 WATTS		LIGHTALL (2)
3.78E-2 (22") 3.15E-2 (8 FT)	610 (14.5")	330	110-20	00-10	30-40	3.01E3 (18")	367.4	N	N	N
3. METAL HALIDE LAMP				MVR 1000/U				1000 WATTS		LIGHTALL (4)
5.17E-2 (22") 4.95E-2 (8 FT)	3010-20 (12")	3910-20	2290	130	530	7.10E3 (18")	406.3	N	N	N
4. HIGH PRESSURE SODIUM LAMP					LUCALUX LU 1000			1000 WATTS		HANGARS, LIGHTALL(2)
556E-2 (22") 3.17E-2 (8 FT)	760-70 (9.5")	1050-60	40-50	10-20	230-40	4.98E4 (18")	534.7	N	N	N

Table 25 (Continued)

ULTRAVIOLET				VISIBLE		INFRARED		FIRE DETECTORS-SINGLE SOURCE		
200 nm $\mu W/cm^2$	254 nm $\mu W/cm^2$	300 nm $\mu W/cm^2$	365 nm $\mu W/cm^2$	405 nm $\mu W/cm^2$	450 nm $\mu W/cm^2$	4.37 μm $\mu W/cm^2$	TEMP. °K	SPECIAL UV FIRE DET.	SPECIAL IR FIRE DET.	ALL OTHER FIRE DET.

GROUP I: Exitances of High Intensity Discharge Lamps (cont'd)

5. METAL HALIDE LAMP — MH 250/U — 250 WATTS — FLOODLAMP

4.84E-2 (18")	1380-90 (6.5")	890-900	740-50	60	150	6.21E3 (18")	399.7	N	N	N

6. MERCURY VAPOR LAMP — H39 KB-175 — 175 WATTS — ROUND ROADWAY LIGHT

3.62E-2 (22")	160-70	80-90	100-110	00-10	00-10	4.51E3 (18")	384.7	N	N	N

7. LOW PRESSURE SODIUM LAMP — SOX 35W L70RB-35 — 35 WATTS — LONG ROADWAY LIGHT

3.06E-2 (22")	00 (12")	00	00	00	00	1.97E3 (18")	350.8	N	N	N

Table 25 (Continued)

Group II: Exitances of Other Radiation Sources

ULTRAVIOLET				VISIBLE		INFRARED		FIRE DETECTORS-SINGLE SOURCE		
200 nm $\mu W/cm^2$	254 nm $\mu W/cm^2$	300 nm $\mu W/cm^2$	365 nm $\mu W/cm^2$	405 nm $\mu W/cm^2$	450 nm $\mu W/cm^2$	4.37 μm $\mu W/cm^2$	TEMP. °K	SPECIAL UV FIRE DET.	SPECIAL IR FIRE DET.	ALL OTHER FIRE DET.
1. QUARTZ TUNGSTEN HALOGEN LAMP										
5.23E-2 (22")	350 (9")	40-50	40-50	2390	190	2.29E4 (18")	474.8	N	N	N
2. YELLOW FLASHING LAMP										
4.95E-5 (22")	00 (16")	00	00	00	00	3.98E2 (18")	299.7	N	N	N
3. RED FLASHING LAMP										
1.82E-2 (22")	00 (14")	00	00	00 TO 100	00	4.05E2 (18")	300.2	N	N	N
4. ULTRAVIOLET BUG LAMP										
1.65E-5 (22")	00 (12")	00	00	00	00	4.05E2 (18")	300.2	N	N	N
5. EASTON HOT PLATE										
1.10E-5 (30")	00 (14")	00	00	00	00	8.54E4 (18")	585.9	N	N	N
6. HAMILTON BEACH HOT PLATE										
8.81E-6 (30")	00 (14")	00	00	00	00	5.05E4 (25")	535.9	N	N	N

Table 25 (Continued)

Group III: Exitances of Other Radiation Sources

ULTRAVIOLET				VISIBLE		INFRARED		FIRE DETECTORS-SINGLE SOURCE		
200 nm $\mu W/cm^2$	254 nm $\mu W/cm^2$	300 nm $\mu W/cm^2$	365 nm $\mu W/cm^2$	405 nm $\mu W/cm^2$	450 nm $\mu W/cm^2$	4.37 μm $\mu W/cm^2$	TEMP. °K	SPECIAL UV FIRE DET.	SPECIAL IR FIRE DET.	ALL OTHER FIRE DET.
1. DUAL FLUORESCENT LAMPS (48")										
2.64E-2 (22")	00 (15")	00-10	00-10	20-30	90	4.80E2 (18")	304.9	N	N	N
2. CLEAR INCANDESCENT LAMP										
4.65E-2 (22")	10-20 (13")	00	00	130	10-00	3.65E3 (18")	375.4	N	N	N
3. WHITE INCANDESCENT LAMP										
3.92E-2 (22")	20 (15")	00	00	150	10	2.95E3 (18")	366.5	N	N	N
4. ULTRAVIOLET LAMP										
9.91E-3 (22")	00 (17") 10 (9")	00 00	00 00	20-30 80	00 00	8.85E3 (18")	417.6	N	N	N
5. TUNGSTEN HALOGEN TRUCK HEADLIGHT										
LOW BEAM X.50E-2 HIGH BEAM 4.24E-2 (22")	140 260-70 (9")	00-10 10-20	10-20 20	3120 4330-40	100 190-200	7.53E2 1.55E3 (18")	318.2 342.0	N	N	N

Table 25 (Continued)

ULTRAVIOLET				VISIBLE		INFRARED		FIRE DETECTORS-SINGLE SOURCE		
200 nm $\mu W/cm^2$	254 nm $\mu W/cm^2$	300 nm $\mu W/cm^2$	365 nm $\mu W/cm^2$	405 nm $\mu W/cm^2$	450 nm $\mu W/cm^2$	4.37 μm $\mu W/cm^2$	TEMP. °K	SPECIAL UV FIRE DET.	SPECIAL IR FIRE DET.	ALL OTHER FIRE DET.

GROUP III: Exitances of Other Radiation Sources (cont'd)

6. F-15 LANDING LIGHT

4.98E-2 (22")	30 (24")	20	10	230	40-30	1.12E4 (18")	450.4	N	N	N

7. SMALL DUAL INCANDESCENT LAMPS

2.58E-3 (22")	00 (14")	00	00	00	00	7.66E2 (18")	318.7	N	N	N

8. F-16 REFUELING LAMPS (3)

X.26E-3 (22")	00 (13")	00	00	20	00	1.43E3 (18")	339.3	N	N	N

Table 26

Tabulated Data of Irradiances of JP-4 Fuel Burns (2' x 2' Pans) and Possible False Alarm Sources as Functions of Distance (0-100 FT.)

JP-4 FUEL BURNS

I. EDWARDS AFB FIELD BURNS

DISTANCE	ULTRAVIOLET		INFRARED
ft.	200 nm Band $\mu W/cm^2$	254 nm Band $\mu W/cm^2$	4.37μm $\mu W/cm^2$-μm
0	2.55E-0	0	Instrument
5	9.91E-2		not operating
10	2.40E-2		properly.
20	5.60E-3		
30	2.37E-3		
40	1.25E-3		
50	7.56E-4		
60	4.95E-4		
70	8.42E-4		
80	2.47E-4		
90	1.84E-4		
100	1.40E-4		

II. LOCAL FIELD BURNS

0	7.09E-1	2.30E3	4.12E5
5	2.75E-2	9.18E1	1.61E4
10	6.66E-3	2.29E1	3.93E3
20	1.57E-3	5.71E0	9.39E2
30	6.58E-4	2.53E0	3.98E2
40	3.48E-4	1.42E0	2.14E2
50	2.10E-4	9.02E-1	1.31E2
60	1.37E-4	6.24E-1	8.66E1
70	9.50E-5	4.57E-1	6.07E1
80	6.85E-5	3.48E-1	4.44E1
90	5.10E-5	2.74E-1	3.35E1
100	3.89E-5	2.21E-1	2.59E1

Table 26 (Continued)

1A. ARC WELDS:

Aluminum, Eutectic Super 2109 Rod

DISTANCE	ULTRAVIOLET		INFRARED
ft.	200 nm Band $\mu W/cm^2$	254 nm Band $\mu W/cm^2$	4.37μm $\mu m/cm^2$-μm
0	4.50E1	7.37E2	2.576
5	1.75E0	2.94E1	1.005
10	4.24E-1	7.34E0	2.454
20	9.98E-2	1.83E0	5.853
30	4.18E-2	8.09E-1	2.483
40	2.21E-2	4.53E-1	1.333
50	1.33E-2	2.89E-1	8.152
60	8.72E-3	2.00E-1	5.402
70	6.03E-3	4.46E-1	3.792
80	4.35E-3	1.12E-1	2.772
90	3.23E-3	8.78E-2	2.092
100	2.47E-3	7.09E-2	1.612

2A. MIG WELD:

Mild Steel, ER 705-6 Wire

0	3.10E1	9.83E2	4.346
5	1.20E0	3.92E1	1.705
10	2.92E-1	9.79E0	4.144
20	6.87.2	2.44E0	9.893
30	2.88E-2	1.08E0	4.193
40	1.52E-2	6.05E-1	2.253
50	9.18E-3	3.86E-1	1.383
60	6.00E-3	2.67E-1	9.122
70	4.15E-3	1.95E-1	6.402
80	2.99E-3	1.49E-1	4.672
90	2.23E-3	1.17E-1	3.532
100	1.70E-3	9.45E-2	2.732

Table 26 (Continued)

LAMPS

1. TFI Lightall Unit: Multivapor Metal Halide, MRV 1000/U

DISTANCE	ULTRAVIOLET		INFRARED
ft.	200 nm Band $\mu W/cm^2$	254 nm Band $\mu W/cm^2$	4.37μm $\mu W/cm^2$-μm
0	1.87E-1	8.60E2	5.96E4
5	7.25E-3	3.43E1	2.33E3
10	1.76E-3	8.57E0	5.69E2
20	4.15E-4	2.13E0	1.36E2
30	1.73E-4	9.44E-1	5.76E1
40	9.19E-5	5.29E-1	3.09E1
50	5.54E-5	3.37E-1	1.89E1
60	3.62E-5	2.33E-1	1.25E1
70	2.51E-5	1.71E-1	8.78E0
80	1.81E-5	1.30E-1	6.42E0
90	1.34E-5	1.02E-1	4.84E0
100	1.03E-5	8.27E-2	3.74E0

2. NF2 Lightall Unit: Mercury Vapor, H33GL-400/DX

0	1.28E-1	8.91E2	6.82E3
5	4.97E-3		2.67E2
10	1.21E-3	3.56E1	6.51E1
20	2.84E-4	2.21E0	1.55E1
30	1.19E-4	9.78E-1	6.59E0
40	6.29E-5	5.48E-1	3.54E0
50	3.79E-5	3.49E-1	2.16E0
60	2.42E-5	2.42E-1	1.43E0
70	1.72E-5	X.77E-1	1.00E0
80	1.24E-5	1.35E-1	7.35E-1
90	9.20E-6	1.06E-1	5.54E-1
100	7.02E-6	8.51E-2	4.28E-1

Table 26 (Continued)

3. NF2D Lightall Unit: High Pressure Sodium, Lucalox LU 1000

DISTANCE	ULTRAVIOLET		INFRARED
ft.	200 nm Band $\mu W/cm^2$	254 nm Band $\mu W/cm^2$	4.37μm $\mu W/cm^2$-μm
0	1.87E-1	7.65E2	1.13E5
5	7.25E-3	3.05E1	4.42E3
10	1.76E-1	7.62E0	1.08E3
20	4.15E-4	1.90E0	2.57E2
30	1.73E-4	8.40E-1	1.09E2
40	9.19E-5	4.71E-1	5.86E1
50	5.54E-5	3.00E-1	3.58E1
60	3.62E-5	2.08E-1	2.37E1
70	2.51E-5	1.52E-1	1.67E1
80	1.81E-5	1.16E-1	1.22E1
90	1.34E-5	9.12E-2	9.18E0
100	1.03E-5	7.36E-2	7.10E0

4. Floodlamp, Rectangular: Metal Halide MH250/U

0	1.10E-1	4.08E2	2.10E4
5	4.27E-3	1.63E1	8.21E2
10	1.04E-3	4.06E0	2.00E2
20	2.44E-4	1.01E0	4.78E1
30	1.02E-4	4.48E-1	2.03E1
40	5.41E-5	2.51E-1	1.09E1
50	3.26E-5	1.60E-1	6.66E0
60	2.13E-5	1.11E-1	4.41E0
70	1.47E-5	8.10E-2	3.09E0
80	1.06E-5	6.18E-2	2.26E0
90	7.91E-6	4.86E-2	1.71E0
100	6.03E-6	3.92E-2	1.32E0

Table 26 (Continued)

5. Floodlamp, Round: Metal Halide, MVR 1500/HBU/E

DISTANCE	ULTRAVIOLET		INFRARED
ft.	200 nm Band $\mu W/cm^2$	254 nm Band $\mu W/cm^2$	4.37μm $\mu W/cm^2$-μm
0	1.87E-1	8.60E2	5.96E4
5	7.25E-3	3.43E1	2.33E3
10	1.76E-3	8.57E0	5.69E2
20	4.15E-4	2.13E0	1.36E2
30	1.73E-4	9.44E-1	5.76E1
40	9.19E-5	5.29E-1	3.09E1
50	5.54E-5	3.37E-1	1.89E1
60	3.62E-5	2.33E-1	1.25E1
70	2.51E-5	1.71E-1	8.78E0
80	1.8E1E-5	1.30E-1	6.42E0
90	1.34E-5	1.02E-1	4.84E0
100	1.03E-5	8.27E-2	3.74E0

6. Long Roadway Light: Low Pressure Sodium, SOX35W, L70RB-35

0	1.04E-1	00	4.46E3
5	1.55E-4		1.74E2
10	3.77E-5		4.26E1
20	8.87E-6		1.02E1
30	3.71E-6		4.31E0
40	1.97E-6		2.31E0
50	1.18E-6		1.41E0
60	7.75E-7		9.37E-1
70	5.36E-7		6.57E-1
80	3.86E-7		4.80E-1
90	2.88E-7		3.62E-1
100	2.19E-7		2.80E-1

Table 26 (Continued)

7. Round Roadway Light: Mercury Vapor, H39KB-175

DISTANCE	ULTRAVIOLET		INFRARED
ft.	200 nm Band $\mu W/cm^2$	254 nm Band $\mu W/cm^2$	4.37μm $\mu W/cm^2$-μm
0	1.23E-1	1.65E2	1.02E4
5	4.77E-3	6.59E0	3.99E2
10	1.16E-3	1.64E0	9.74E1
20	2.73E-4	4.09E-1	2.32E1
30	1.14E-4	1.81E-1	9.86E0
40	6.04E-5	1.02E-1	5.29E0
50	3.64E-5	6.47E-2	3.23E0
60	2.38E-5	4.48E-2	2.14E0
70	1.65E-5	3.28E-2	1.50E0
80	1.19E-5	2.50E-2	1.10E0
90	8.04E-6	1.97E-2	8.29E-1
100	6.74E-6	1.59E-2	6.41E-1

8. F-16 Aircraft Landing Light: Incandescent Sealed Beam, GE 4581

0	1.69E-1	1.20E2	2.59E4
5	6.56E-3	4.79E0	9.93E2
10	1.59E-3	1.20E0	2.42E2
20	3.75E-4	2.98E-1	5.79E1
30	1.57E-4	1.32E-1	2.45E1
40	8.31E-5	7.38E-2	1.32E1
50	5.01E-5	4.71E-2	8.05E0
60	3.27E-5	3.26E-2	5.34E0
70	2.26E-5	2.38E-2	3.74E0
80	1.63E-5	1.82E-2	2.74E0
90	1.21E-5	1.43E-2	2.06E0
100	9.27E-6	1.15E-2	1.60E0

Table 26 (Continued)

9. F-16 Aircraft Refueling Lights (3): 4028-1

DISTANCE	ULTRAVIOLET		INFRARED
ft.	200 nm Band	254 nm Band	4.37μm
0	2.81E-2	00	3.24E3
5	1.09E-3		1.27E2
10	2.65E-4		3.09E1
20	6.23E-5		7.38E0
30	2.61E-5		3.13E0
40	1.38E-5		1.68E0
50	8.32E-6		1.03E0
60	5.44E-6		6.81E-1
70	3.77E-6		4.77E-1
80	2.71E-6		3.49E-1
90	2.02E-6		2.63E-1
100	1.54E-6		2.03E-1

10. Small Incandescent Bulbs (2): 1829

0	8.76E-3	00	1.74E3
5	3.40E-4		6.80E1
10	8.25E-5		1.66E1
20	1.94E-5		3.96E0
30	8.13E-6		1.68E0
40	4.31E-6		9.03E-1
50	2.59E-6		5.52E-1
60	1.70E-6		3.66E-1
70	1.17E-6		2.56E-1
80	8.46E-7		1.87E-1
90	6.30E-7		1.41E-1
100	4.80E-7		1.09E-1

Table 26 (Continued)

11. Quartz Tungsten Halogen Work Light: 300 Watts

DISTANCE	ULTRAVIOLET		INFRARED
ft.	200 nm Band $\mu W/cm^2$	254 nm Band $\mu W/cm^2$	4.37μm $\mu W/cm^2$-μm
0	1.78E-1	3.5017E-2	5.19E4
5	6.91E-3	1.40E	2.03E3
10	1.68E-3	3.49E0	4.95E2
20	3.95E-4	8.69E-1	1.18E2
30	1.65E-4	3.85E-1	5.02E1
40	8.75E-5	2.15E-1	2.69E1
50	5.27E-5	1.37E-1	1.65E1
60	3.45E-5	9.50E-2	1.09E1
70	2.39E-5	6.95E-2	7.65E0
80	1.72E-5	5.30E-2	5.59E0
90	1.28E-5	4.17E-2	4.22E0
100	9.75E-6	3.37E-2	3.26E0

12. Truck Incandescent Sealed Beam Headlight: GE 4811

	LOW BEAM			HIGH BEAM		
DISTANCE	UV-200	UV-254	IR-4.37	UV-200	UV-254	IR-4.37
0	8.49E-2	4.71E2	1.71E3	1.44E-1	1.49E2	3.49E3
5	3.30E-3	4.88E1	6.68E1	5.59E-3	5.95E0	1.39E2
10	7.99E-4	4.69E0	1.63E1	1.36E-3	1.48E0	3.47E1
20	1.88E-4	1.17E0	3.90E0	3.19E-4	3.70E-1	8.64E0
30	7.88E-5	5.17E-1	1.65E0	1.34E-4	1.64E-1	3.82E0
40	4.17E-5	2.90E-1	8.87E-1	7.08E-5	9.17E-2	2.14E0
50	2.51E-5	1.85E-1	5.42E-1	4.27EE-5	5.84E-2	1.36E0
60	1.64E-5	1.28E-1	3.59E-1	2.79E-5	4.04E-2	9.43E-
70	1.14E-5	9.35E-2	2.52E-1	1.93E-5	2.96E-2	6.89E-
80	8.20E-6	7.13E-2	1.84E-1	1.39E-5	2.26E-2	5.25E-
90	6.10E-6	5.61E-2	1.39E-1	1.04E-5	1.78E-2	4.13E-
100	4.65E-6	4.53E-2	1.07E-1	7.90E-6	1.43E-2	3.33E-

Table 26 (Continued)

13. Revolving Yellow Strobe Light: Tandy 49-527

DISTANCE	ULTRAVIOLET		INFRARED
ft.	200 nm Band $\mu W/cm^2$	254 nm Band $\mu W/cm^2$	4.37μm $\mu W/cm^2$-μin
0	1.68E-4	00	9.02E2
5	6.52E-6		3.53E1
10	1.58E-6		8.61E0
20	3.72E-7		2.05E0
30	1.56E-7		8.72E-1
40	8.26E-8		4.68E-1
50	4.98E-8		2.86E-1
60	3.25E-8		1.90E-1
70	2.25E-8		1.33E-1
80	1.62E-8		9.71E-2
90	1.21E-8		7.33E-2
100	9.21E-9		5.67E-2

14. Revolving Red Strobe Light: Tandy 42-3040

0	6.18E-2	00	9.18E2
5	2.40E-3		3.59E1
10	5.82E-4		8.76E0
20	1.37E-4		2.09E0
30	5.73E-5		8.87E-1
40	3.03E-5		4.76E-1
50	2.83E-5		2.91E-1
60	1.20E-5		1.92E-1
70	8.28E-5		1.35E-1
80	5.97E-6		9.89E-2
90	4.44E-6		7.46E-2
100	3.39E-6		5.77E-2

Table 26 (Continued)

15. Ultraviolet "Black Lamp": Feit Electric 75 A/BL

DISTANCE	ULTRAVIOLET		INFRARED
ft.	200 nm Band $\mu W/cm^2$	254 nm Band $\mu W/cm^2$	4.37μm $\mu W/cm^2$-μm
0	3.37E-2	5.63E0	2.01E4
5	1.31E-3	2.25E-1	7.86E2
10	3.17E-4	5.61E-2	1.92E2
20	7.47E-5	1.40E-2	4.58E1
30	3.13E-5	6.18E-3	1.94E1
40	1.66E-5	3.46E-3	1.04E1
50	9.98E-6	2.21E-3	6.37E0
60	6.53E-6	1.53E-3	4.22E0
70	4.52E-6	1.12E-3	2.96E0
80	3.26E-6	8.53E-4	2.16E0
90	2.42E-6	6.71E-4	1.63E0
100	1.85E-6	5.41E-4	1.26E0

16. Soft White Incandescent Lamp: GE Soft White

0	1.33E-1	3.13E1	6.68E3
5	5.16E-3	1.25E0	2.61E2
10	1.25E-3	3.11E-1	6.38E1
20	2.95E-4	7.76E-2	1.52E1
30	1.23E-4	3.43E-2	6.46E0
40	6.54E-5	1.92E-2	3.47E0
50	3.94E-5	1.23E-2	2.12E0
60	2.58E-5	8.48E-3	1.40E0
70	1.78E-5	6.21E-3	9.84E-1
80	1.28E-5	4.73E-3	7.19E-1
90	9.56E-6	3.72E-3	5.43E-1
100	7.29E-6	3.01E-3	4.20E-1

Table 26 (Continued)

17. Clear Incandescent Lamp: GE Crystal Clear

DISTANCE	ULTRAVIOLET		INFRARED
ft.	200 nm Band $\mu W/cm^2$	254 nm Band $\mu W/cm^2$	4.37μm $\mu W/cm^2$-μm
0	1.58E-1	1.76E1	8.27E3
5	6.13E-3	7.03E-1	3.23E2
10	1.49E-3	1.75E-1	7.89E1
20	3.50E-4	4.37E-2	1.88E1
30	1.47E-4	1.93E-2	7.99E0
40	7.76EE-5	1.08E-2	4.29E0
50	4.68E-5	6.91E-3	2.62E0
60	3.06E-5	4.78E-3	1.74E0
70	2.12E-5	3.50E-3	1.22E0
80	1.53E-5	2.67E-3	8.91E-1
90	1.14E-5	2.10E-3	6.72E-1
100	8.66E-6	1.69E-3	5.19E-1

18. Dual Fluorescent Lamp Workshop Fixture: Sylvania F 4c Rapid Start, 48 inch length

0	8.97E-2	00	1.09E3
5	3.48E-3		4.26E1
10	8.45E-4		1.04E1
20	1.99E-4		2.48E0
30	8.32E-5		1.05E0
40	4.41E-5		5.66E-1
50	2.66E-5		3.46E-1
60	1.74E-5		2.29E-1
70	1.28E-5		1.61E-1
80	8.67E-6		1.17E-1
90	6.45E-6		8.85E-2
100	4.92E-6		6.85E-2

Table 26 (Continued)

19. Hot Plate: Hamilton Beach, 812-4, 750 Watts

DISTANCE	ULTRAVIOLET		INFRARED
ft.	200 nm Band $\mu W/cm^2$	254 nm Band $\mu W/cm^2$	4.37μm $\mu W/cm^2$-μm
0	2.17E-6	00	2.21E5
5	8.42E-8		8.64E3
10	2.04E-8		2.11E3
20	4.81E-9		5.03E2
30	2.01E-9		2.14E2
40	1.07E-9		1.15E2
50	6.43E-10		7.01E1
60	4.20E-10		4.64E1
70	2.91E-10		3.26E1
80	2.10E-10		2.38E1
90	1.56E-10		1.80E1
100	1.19E-10		1.39E1

20. Hot Plate: Eastern Electric, SB 101 W, 1000 Watts

0	6.87E-5	00	3.74E5
5	2.67E-6		1.46E4
10	6.47E-7		3.57E3
20	1.52E-7		8.52E2
30	6.37E-8		3.61E2
40	3.38E-8		1.94E2
50	2.03E-8		1.19E2
60	1.33E-8		7.86E1
70	9.21E-9		5.51E1
80	6.64E-9		4.03E1
90	4.94E-9		3.04E1
100	3.77E-9		2.35E1

Table 26 (Continued)

21. Quartz Tungsten Halogen Lamp: Colortran 1000, 1000W

DISTANCE	ULTRAVIOLET		INFRARED
ft.	200 nm Band $\mu W/cm^2$	254 nm Band $\mu W/cm^2$	4.37μm $\mu W/cm^2$-μm
0	9.18E-1		
5	3.56E-2		
10	8.64E-3		
20	2.04E-3		
30	8.52E-4		
40	4.51E-4		
50	2.72E-4		
60	1.78E-4		
70	1.23E-4		
80	8.87E-5		
90	6.60E-5		
100	5.03E-5		

22. Metal Halide Lamp: MVR 1000/U 1000 Watts

0	1.76E-1	3.015E3	1.61E4
5	6.91E-3	1.20E2	6.29E2
10	1.68E-3	3.00E1	1.54E2
20	3.95E-4	7.48E0	3.67E1
30	1.65E-4	3.31E0	1.56E1
40	8.75E-5	1.86E0	8.35E0
50	5.27E-5	1.18E0	5.10E0
60	3.45E-5	8.18E-1	3.38E0
70	2.39E-5	5.99E-1	2.37E0
80	1.72E-5	4.57E-1	1.73E0
90	1.28E-5	3.59E-1	1.31E0
100	9.75E-6	2.90E-1	1.01E0

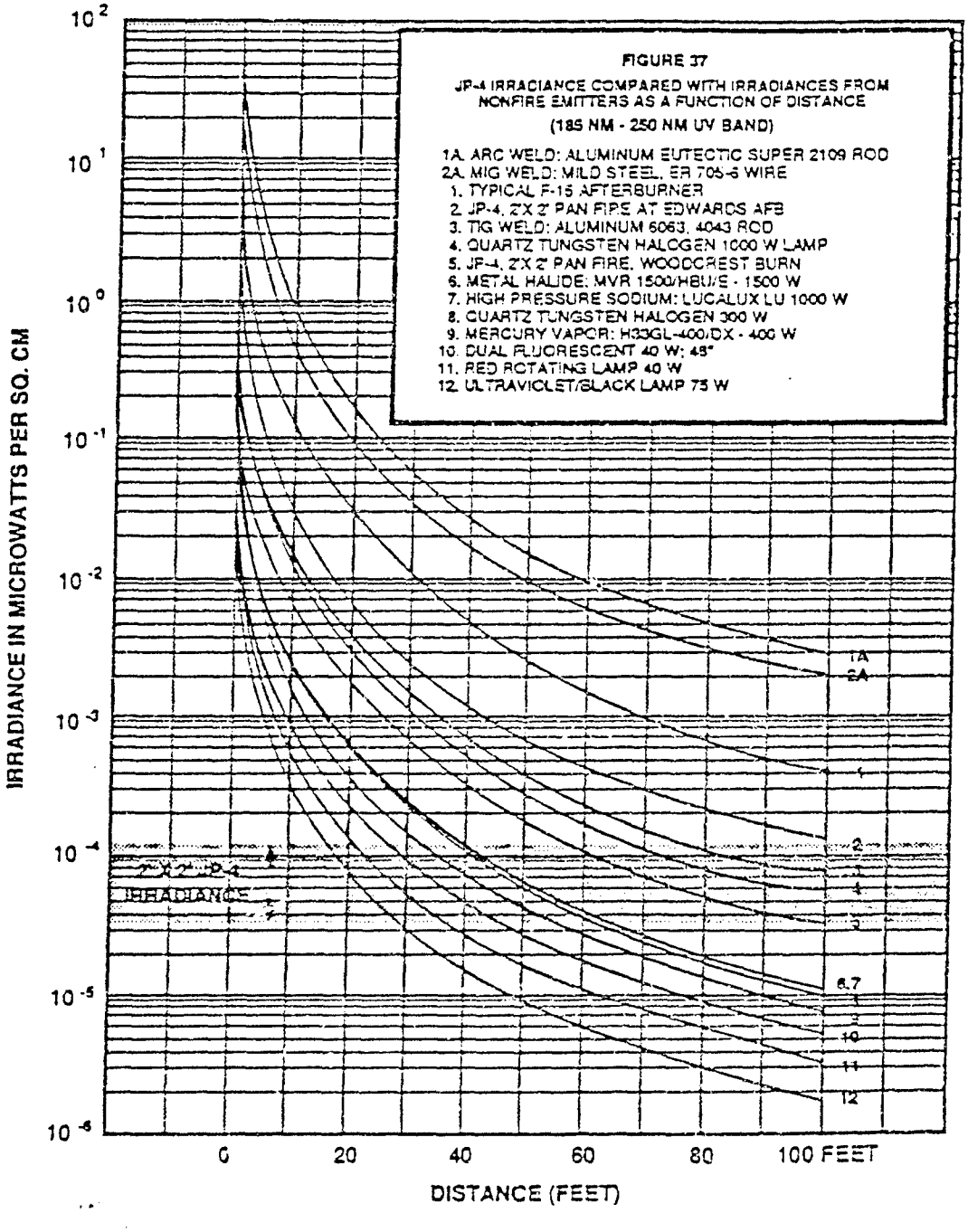


FIGURE 37
JP-4 IRRADIANCE COMPARED WITH IRRADIANCES FROM NONFIRE EMITTERS AS A FUNCTION OF DISTANCE
(185 NM - 250 NM UV BAND)
1A. ARC WELD: ALUMINUM EUTECTIC SUPER 2109 ROD
2A. MIG WELD: MILD STEEL, ER 705-6 WIRE
1. TYPICAL F-15 AFTERBURNER
2. JP-4, 2'X 2' PAN FIRE AT EDWARDS AFB
3. TIG WELD: ALUMINUM 6063, 4043 ROD
4. QUARTZ TUNGSTEN HALOGEN 1000 W LAMP
5. JP-4, 2'X 2' PAN FIRE, WOODCREST BURN
6. METAL HALIDE: MVR 1500/HBU/E - 1500 W
7. HIGH PRESSURE SODIUM: LUCALUX LU 1000 W
8. QUARTZ TUNGSTEN HALOGEN 300 W
9. MERCURY VAPOR: H33GL-400/DX - 400 W
10. DUAL FLUORESCENT 40 W; 48"
11. RED ROTATING LAMP 40 W
12. ULTRAVIOLET/BLACK LAMP 75 W
IRRADIANCE IN MICROWATTS PER SQ. CM
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
2' X 2' JP-4 IRRADIANCE
1A
2A
1
2
4
3
6,7
10
11
12
0
20
40
60
80
100 FEET
DISTANCE (FEET)

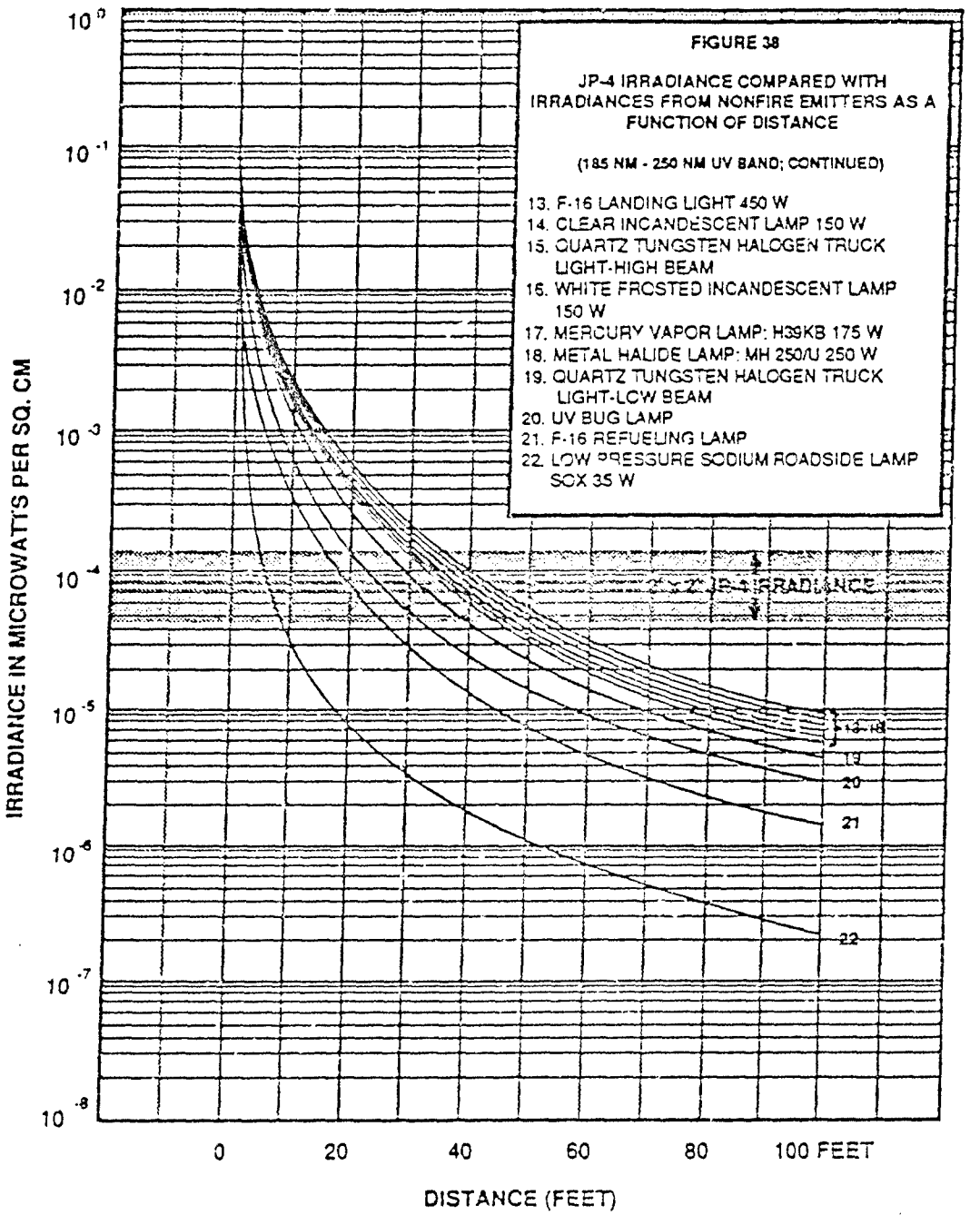


FIGURE 38
JP-4 IRRADIANCE COMPARED WITH IRRADIANCES FROM NONFIRE EMITTERS AS A FUNCTION OF DISTANCE
(185 NM - 250 NM UV BAND; CONTINUED)
13. F-16 LANDING LIGHT 450 W
14. CLEAR INCANDESCENT LAMP 150 W
15. QUARTZ TUNGSTEN HALOGEN TRUCK LIGHT-HIGH BEAM
16. WHITE FROSTED INCANDESCENT LAMP 150 W
17. MERCURY VAPOR LAMP: H39KB 175 W
18. METAL HALIDE LAMP: MH 250/U 250 W
19. QUARTZ TUNGSTEN HALOGEN TRUCK LIGHT-LOW BEAM
20. UV BUG LAMP
21. F-16 REFUELING LAMP
22. LOW PRESSURE SODIUM ROADSIDE LAMP SOX 35 W
JP-4 IRRADIANCE
IRRADIANCE IN MICROWATTS PER SQ. CM
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
0
20
40
60
80
100 FEET
DISTANCE (FEET)

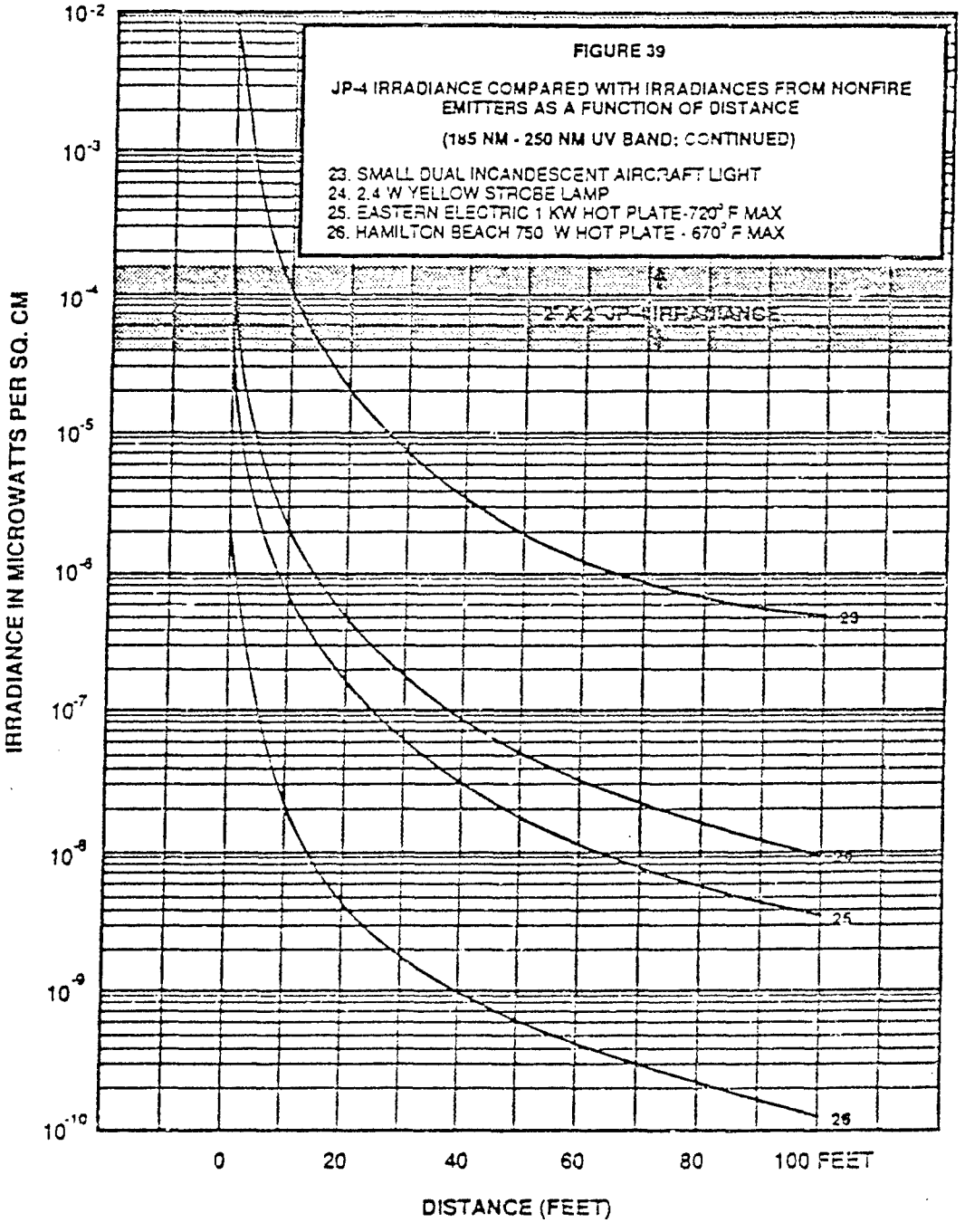


FIGURE 39
JP-4 IRRADIANCE COMPARED WITH IRRADIANCES FROM NONFIRE EMITTERS AS A FUNCTION OF DISTANCE
(185 NM - 250 NM UV BAND; CONTINUED)
23. SMALL DUAL INCANDESCENT AIRCRAFT LIGHT
24. 2.4 W YELLOW STROBE LAMP
25. EASTERN ELECTRIC 1 KW HOT PLATE-720° F MAX
26. HAMILTON BEACH 750 W HOT PLATE - 670° F MAX
2" X 2" JP-4 IRRADIANCE
IRRADIANCE IN MICROWATTS PER SQ. CM
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
23
25
26
0
20
40
60
80
100 FEET
DISTANCE (FEET)

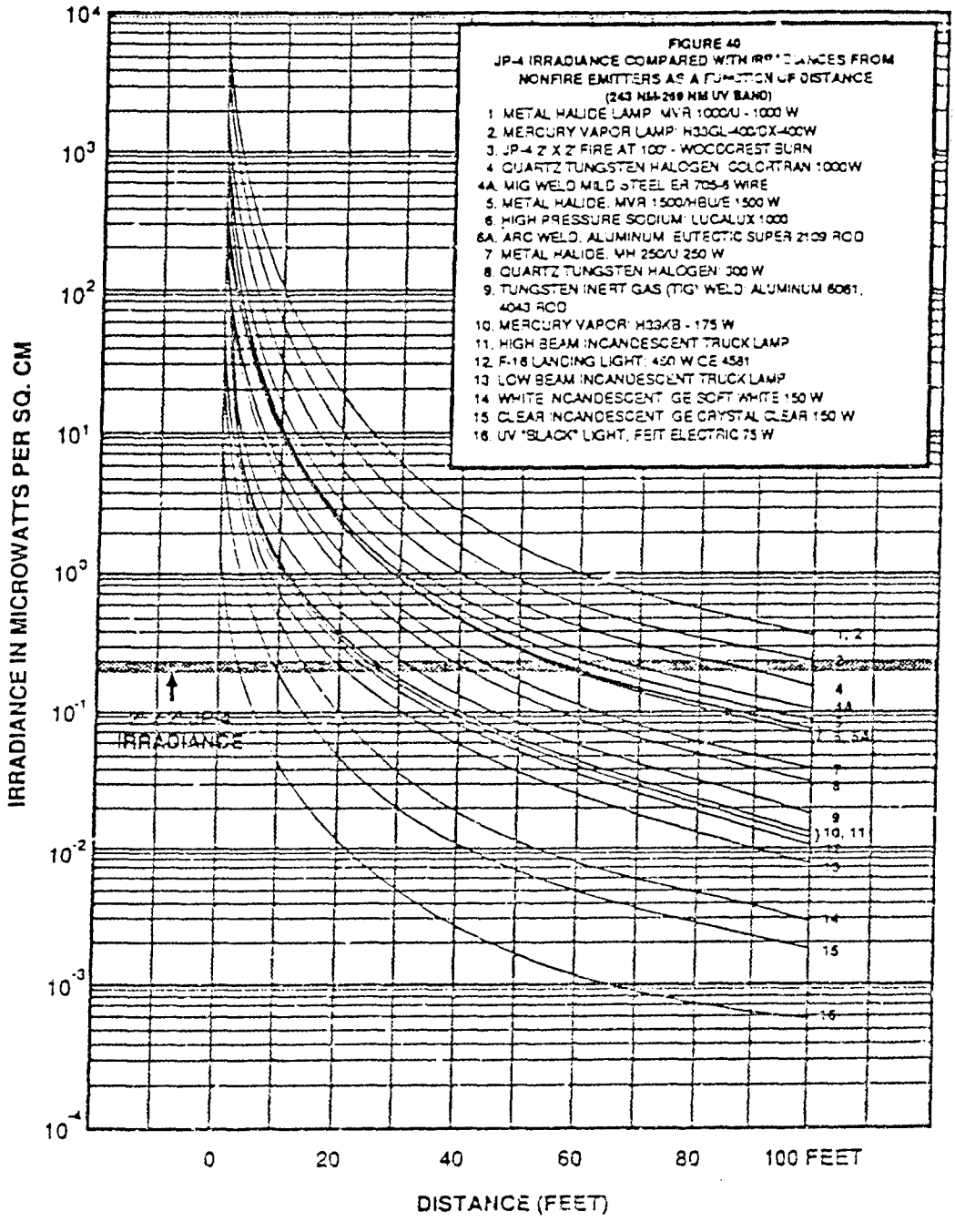


FIGURE 40
JP-4 IRRADIANCE COMPARED WITH IRRADIANCES FROM NONFIRE EMITTERS AS A FUNCTION OF DISTANCE
(243 NM-280 NM UV BAND)
1. METAL HALIDE LAMP: MVR 1000/U - 1000 W
2. MERCURY VAPOR LAMP: H33GL-400/DX-400W
3. JP-4 2' X 2' FIRE AT 100' - WOODCREST BURN
4. QUARTZ TUNGSTEN HALOGEN: COLORTRAN 1000W
4A. MIG WELD MILD STEEL ER 705-6 WIRE
5. METAL HALIDE: MVR 1500/HBU/E 1500 W
6. HIGH PRESSURE SODIUM: LUCALUX 1000
6A. ARC WELD, ALUMINUM: EUTECTIC SUPER 2139 RCO
7. METAL HALIDE: MH 250/U 250 W
8. QUARTZ TUNGSTEN HALOGEN: 300 W
9. TUNGSTEN INERT GAS (TIG) WELD: ALUMINUM 6061, 4043 RCO
10. MERCURY VAPOR: H33/KB - 175 W
11. HIGH BEAM INCANDESCENT TRUCK LAMP
12. F-16 LANDING LIGHT: 450 W CE 4581
13. LOW BEAM INCANDESCENT TRUCK LAMP
14. WHITE INCANDESCENT: GE SOFT WHITE 150 W
15. CLEAR INCANDESCENT: GE CRYSTAL CLEAR 150 W
16. UV "BLACK" LIGHT: FEIT ELECTRIC 75 W
IRRADIANCE IN MICROWATTS PER SQ. CM
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
IRRADIANCE
1, 2
4
4A
8
9
10, 11
15
0
20
40
60
80
100 FEET
DISTANCE (FEET)

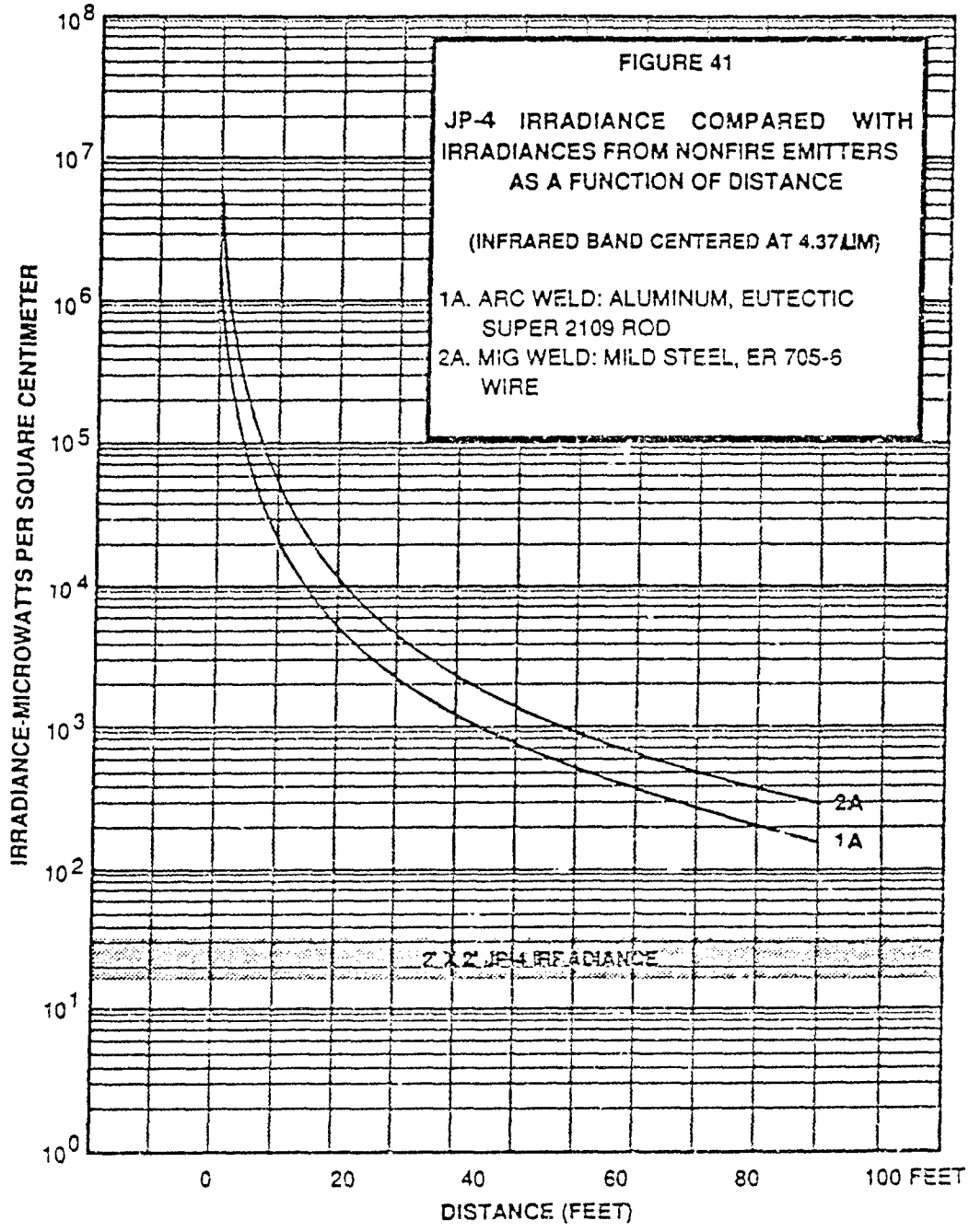


FIGURE 41
JP-4 IRRADIANCE COMPARED WITH IRRADIANCES FROM NONFIRE EMITTERS AS A FUNCTION OF DISTANCE
(INFRARED BAND CENTERED AT 4.37 μM)
1A. ARC WELD: ALUMINUM, EUTECTIC SUPER 2109 ROD
2A. MIG WELD: MILD STEEL, ER 705-6 WIRE
IRRADIANCE-MICROWATTS PER SQUARE CENTIMETER
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^1
10^0
2A
1A
2 X 2' JP-4 IRRADIANCE
0
20
40
60
80
100 FEET
DISTANCE (FEET)

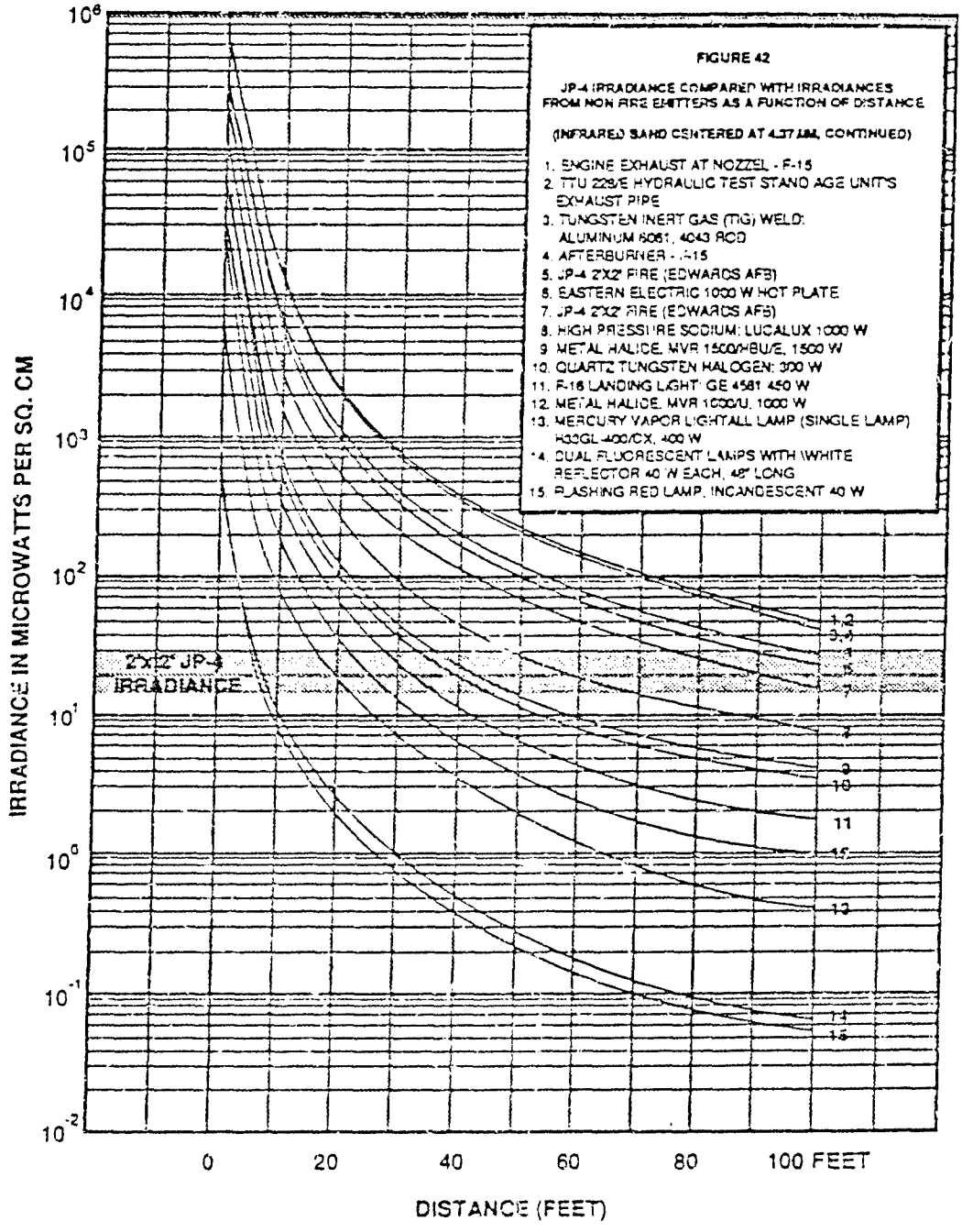


FIGURE 42
JP-4 IRRADIANCE COMPARED WITH IRRADIANCES FROM NON FIRE EMITTERS AS A FUNCTION OF DISTANCE
(INFRARED BAND CENTERED AT 4.37 μM, CONTINUED)
1. ENGINE EXHAUST AT NOZZEL - F-15
2. TTU 228/E HYDRAULIC TEST STAND AGE UNIT'S EXHAUST PIPE
3. TUNGSTEN INERT GAS (TIG) WELD: ALUMINUM 5061, 4043 ROD
4. AFTERBURNER - F-15
5. JP-4 2'X2' FIRE (EDWARDS AFB)
6. EASTERN ELECTRIC 1000 W HOT PLATE
7. JP-4 2'X2' FIRE (EDWARDS AFB)
8. HIGH PRESSURE SODIUM: LUCALUX 1000 W
9. METAL HALIDE, MVR 1500/HBU/E, 1500 W
10. QUARTZ TUNGSTEN HALOGEN: 300 W
11. F-16 LANDING LIGHT GE 4581 450 W
12. METAL HALIDE, MVR 1000/U, 1000 W
13. MERCURY VAPOR LIGHTALL LAMP (SINGLE LAMP) H33GL-400/CX, 400 W
14. DUAL FLUORESCENT LAMPS WITH WHITE REFLECTOR 40 W EACH, 48" LONG
15. FLASHING RED LAMP, INCANDESCENT 40 W
2'x2' JP-4 IRRADIANCE
IRRADIANCE IN MICROWATTS PER SQ. CM
10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
0
20
40
60
80
100 FEET
DISTANCE (FEET)

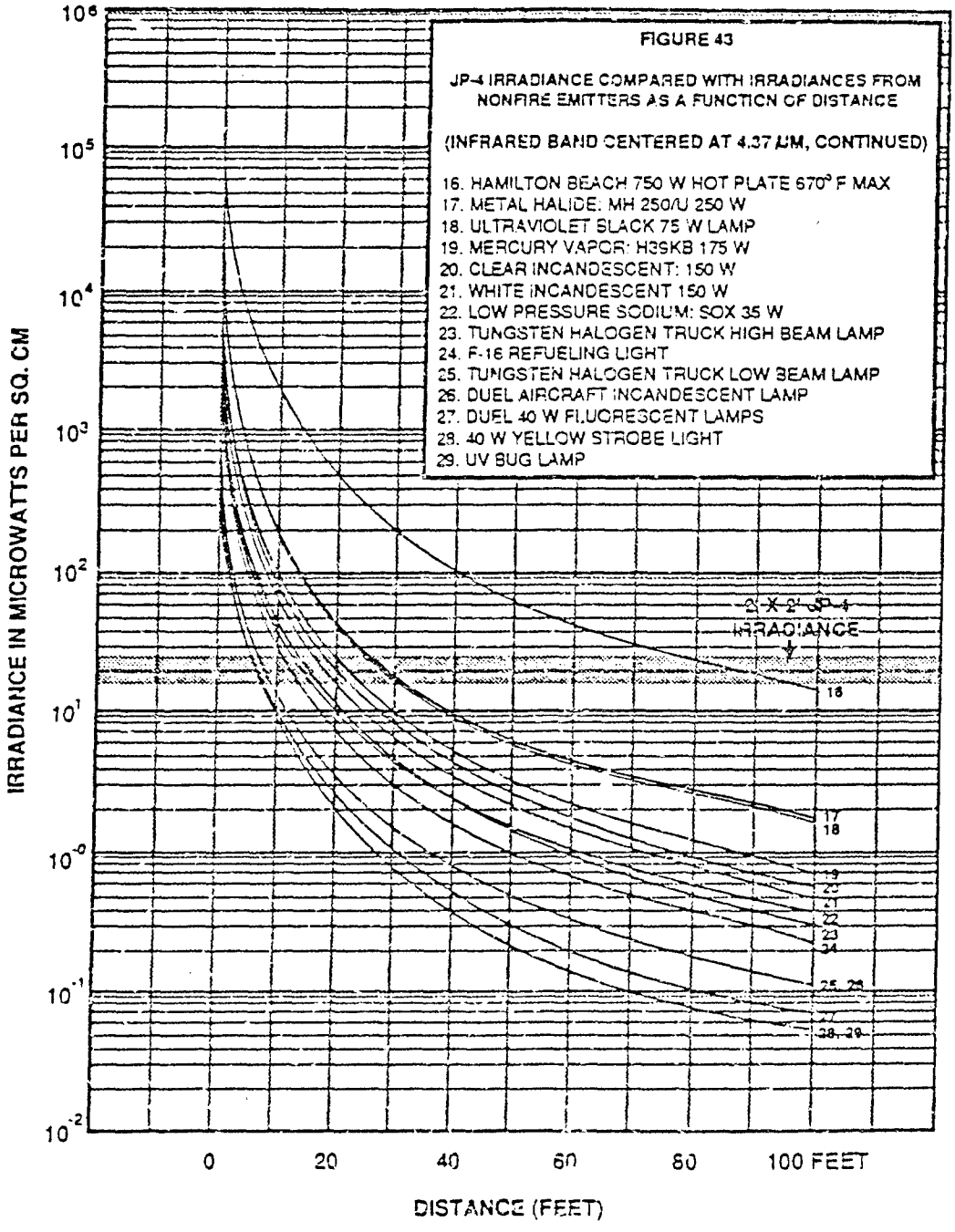


FIGURE 43
JP-4 IRRADIANCE COMPARED WITH IRRADIANCES FROM NONFIRE EMITTERS AS A FUNCTION OF DISTANCE
(INFRARED BAND CENTERED AT 4.37 μM, CONTINUED)
16. HAMILTON BEACH 750 W HOT PLATE 670° F MAX
17. METAL HALIDE: MH 250/U 250 W
18. ULTRAVIOLET BLACK 75 W LAMP
19. MERCURY VAPOR: H3SKB 175 W
20. CLEAR INCANDESCENT: 150 W
21. WHITE INCANDESCENT 150 W
22. LOW PRESSURE SODIUM: SOX 35 W
23. TUNGSTEN HALOGEN TRUCK HIGH BEAM LAMP
24. F-16 REFUELING LIGHT
25. TUNGSTEN HALOGEN TRUCK LOW BEAM LAMP
26. DUEL AIRCRAFT INCANDESCENT LAMP
27. DUEL 40 W FLUORESCENT LAMPS
28. 40 W YELLOW STROBE LIGHT
29. UV BUG LAMP
IRRADIANCE IN MICROWATTS PER SQ. CM
10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
IRRADIANCE
16
17
18
19
20
21
22
23
24
25, 26
27
28, 29
0
20
40
60
80
100 FEET
DISTANCE (FEET)

Table 26 includes the computed "irradiance versus distance" values for almost all the radiation sources listed in Table 24. To these were added several other notable radiation sources measured in the field at Edwards AFB, such as JP-4 fuel burns, MIG, TIG, and Arc welding, many Aircraft Ground Equipment units, and a photographic floodlight set of lamps. This same procedure can be applied to every radiation source once its exitance is properly measured.

Taking the data of Table 26, semilog plots are then made of "irradiance versus distance", resulting in the curves of Figures 37 through 43. Each Figure includes whatever data has been established regarding JP-4 fuel burns for that band. One of the most common performance criteria that the Air Force has set for most fire detectors is that it must be able to detect a 2 ft x 2 ft square pan fire of JP-4 fuel at a distance of 100 feet in 5 seconds or less (after the fire has reached full size). The horizontal straight line across each figure corresponds to the irradiance value from such a "design performance fire" for the spectral band being considered. Where two horizontal lines occur, this helps to point out that there is no single unique value of irradiance for burning JP-4 at 100 feet distance. It is found each pan fire can vary in this respect, depending on a variety of conditions, such as wind. Hence, a spread of values is to be expected. The horizontal lines used here are based upon the actual JP-4-burn measurements.

With the horizontal straight lines serving as the "Air Force criteria" to be satisfied, all curves that extend above these lines show irradiance values that could trigger false alarms (again assuming a 2' x 2' JP-4 fire at 100'). This is true over the range of distances where each curve goes above the Air Force Criterion. Should the Air Force Criterion differ as to the fire type, size, and distance, a separate horizontal irradiance line would have to be determined for each.

For the distances where the curves are below the Air Force criterion, however, each radiation source individually would not have sufficient irradiance to trigger a false alarm. By superimposing additively the irradiances of two or more sources at such distances, it is possible to obtain a combined irradiance that may trigger a false alarm. Such combinations could be estimated from the curves.

Study across all curves of the three bands shows that the steepest rolloff is typically within about the first 20 feet. Thereafter the rolloff of irradiance with distance is more and more gradual.

Hence, it should be possible to experimentally verify whether:

1. Individual radiation sources can trigger a false alarm within the distance over which their irradiance exceeds the Air Force criterion;

2. Individual radiation sources cannot trigger a false alarm for distances where their irradiance is below the Air Force criterion;

3. A combination of radiation sources of the kind in (2) above can be combined to trigger a false alarm.

Each of the above possibilities have been investigated in a preliminary fashion, and each can be demonstrated, with some qualifications. This is clarified below.

What is not shown about these detectors is their actual sensitivity settings and any other special design features for ensuring correct fire discrimination from false alarm sources. In addition to spectral irradiance, each detector had some different discriminatory process as part of its decision process.

These detectors were used in tests to verify that the proposed qualification test procedures could be performed and were repeatable. Care was taken to assure that no comparisons per se were made between commercial detectors' responses to false alarm sources, or for that matter fire sources. Not all detectors were used at the same time in performing these investigations. When one or more detectors responded with an alarm to one or a combination of two or more false alarm sources at various distances and radiation "chopping" frequencies, other detectors were also checked to determine if a malfunction or some peculiarity existed in the procedures.

The detector manufacturers were asked to set their detectors at the following fire threshold: 2-foot x 2-foot JP-4 pan fire at 100 feet, within 5 seconds of the fire attaining full size. This is the standard Air Force specification (Air Force Requirement AFR 88-15, Criteria And Standards For Air Force Construction, January 1986) for fire detectors in hangars and shelters, although some other more sophisticated "system" performance specifications call for different sizes at different distances. The purpose of asking for this setting was to have some basis of commonality between detectors used in the development and verification of the qualification test procedures. It was found that the "fire detection threshold" of each detector differed somewhat against the same sources (butane flame and propane flame) at the same distance.

As shown in Figure 44, the detectors were mounted on a mobile fixture in such a manner as to assure no obstructions to

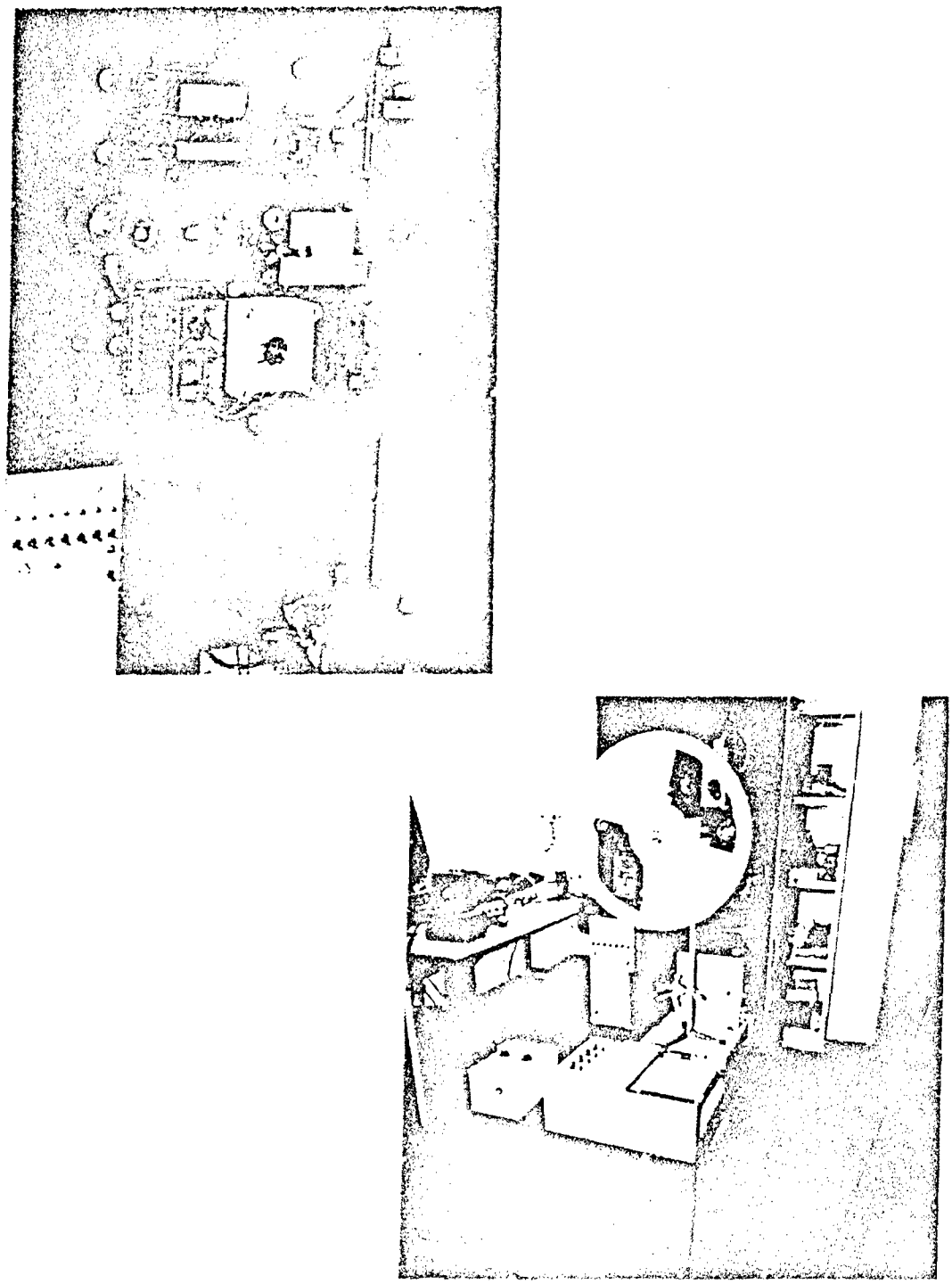


Figure 44. Mobile Detector Fixture (Showing Eight Detectors and How Chopper Wheel Fits Over the Detectors).

their FOVs. The detector outputs were monitored by LEDs that illuminated when the detector responded with a "fire" signal. The straight UV and straight IR detectors were used to check calculated irradiances against measured irradiances and detector responses (or non responses). They were also used in field tests of fire and false alarm source irradiance measurements.

As shown in Figure 34, the false alarm source items listed in Table 24, Section VI, were mounted on three separate mobile fixtures, along with their ballasts and power supplies. These mobile fixtures were then placed at various locations and distances from each other and the detectors, and in some cases were used to simulate a moving vehicle, aircraft, or AGE (aircraft ground equipment) item.

The detectors were utilized in the conduct of a variety of test procedures, specifically identified in Appendix II. Some of the more simple tests performed are listed in Table 28. Note that many other tests were performed with combinations of sources configured according to "real-life" operational scenarios.

Table 28

Basic False Alarm Tests To Single Sources

Test 1:	The radiation sources (s) and detectors are separated at various distances. At each selected distance, after 30 minutes of radiation source operation, the detector is subjected to an "on-off" switching rate of 1 second on and 1 second off, 5 consecutive times. The detector is then left on and the radiation source (s) switched on and off 5 times at 1 minute intervals, if applicable/allowable by the nature of the source.
Test 2:	Each radiation source, at its respective distance from the detector, is then chopped at the following rates with a chopper fan located about 10 inches from the face of the detector: (1) 2 Hz; (2) 10 Hz; and (3) optionally 5 Hz.
Test 3:	If applicable, the glass lens cover plate is removed, and Test 2 repeated.

Test 4: If applicable, the glass lens cover plate is removed, and Test 1 is repeated at its respective distance.

To minimize unnecessary extensive testing, a method of elimination was devised whereby radiation sources not causing the detectors to trigger at a close range of 5 feet, were not used for study at the greater distances, although they, in combination with other sources could additively increase the irradiance value.

Tables 29 and 30 show the response of the detectors to each radiation source studied at a distance of 5 feet to 25 feet. Several sources were then studied in combination, and results are given toward the end of Tables 29 and 30.

The four basic tests were then applied to all the radiation sources in Table 24, with the purpose of comparing expected detector responses with actual responses from a large variety of functional detector types. These comparisons were made, in general, as a function of distance, as the eight detectors were moved incrementally in short successive steps of distance away from the sources to the maximum distance of 25 feet. The results of the study are given in Table 31.

In comparing the results in the tables with the curves, it is very important to note that the curves are based on a steady, unmodified flux of light from the radiation source, and therefore the range-distance associated with the full fluxes are what could be expected with unchopped light. The tables giving the results of the four tests at the different distances, however, are for the same light, but chopped.

Careful consideration of the chopped versus the unchopped light fluxes shows two important differences: (1) the chopped light fluxes are less than the unchopped; and (2) therefore the range-distances will be less for the chopped light than for the unchopped light.

Because the chopper wheel has designed into it a 50% duty factor, regardless of frequency, only half as much light, therefore will reach the detectors. Moreover, when the chopping frequency is taken into consideration, each cycle has a certain length of on-time and off-time. A cycle period, therefore, can have impact on whatever has been designed into the detector for flicker and/or frequency discrimination. The frequencies used here have the following associated parameters:

Frequency Hz	On & Off Times Per Cycle	Period Per Cycle	Percent Of Total Flux Per Flash
2	250 msec	500 msec	25%

5	100 msec	200 msec	10%
10	50 msec	100 msec	5%
60	8.3 msec	16.6 msec	.8%
120	4.2 msec	8.3 msec	.4%

The values for 60 and 120 Hz are included because many of the lamps are AC operated. The HID lamps, for example, are operated at 60 Hz, but turn on and off 120 times a second. The combined effect of "operating frequency" and "chopping frequency" hence reduces radiation source flux to the detector, and impacts the response to frequencies intrinsically designed into each

Table 29
Response of OFDs to Sensors or Source Chopping

SOURCE NO.	SOURCE	TEST NO.	DISTANC FT.	CHOPPER hz	RESPONSE
1	TF1 Lightall	1	5	0	O
	Metal	2		2	O
	Halide			5	O
	MVR 1000/U			10	O
		3		2	O
				5	O
				10	O
		4		0	O
2	NF2 Lightall	1	5	0	O
	Mercury Vapor	2		2,5,10	O,O,O
	H33 GL-400/DX	3		2	D,G IR UV/IR
				5	C,D,G UV IR UV/IR
				10	B,D,G IR, IR UV/IR
		4		0	O
3	NF2 Lightall	1	5	0	G UV/IR
	High Pressure Sodium	2		2	B,G IR, UV/IR
	Lucalox LU 1000			5	B,G IR, UV/IR
				10	B,G IR, UV/IR
		3		2	G UV/IR
				5	B,D,G IR, IR UV/IR
				10	B,D,G IR, IR UV/IR
		4		0	O
4	Rectangular Flood	1	10	0	O
	Metal Halide	2		2,10	O,O
	MH 250/U	3		2	B IR,
				10	O
		4		0	O
5	Round Flood	1	10	0	B,C,D,G IR, UV IR UV/IR

Table 29 (Continued)

SOURCE NO.	SOURCE	TEST NO.	DISTANC FT.	CHOPPER hz	RESPONSE				
	Metal Halide	2		2	B,C,D,G	IR,	UV	IR	UV/IR
	MVR 1500/HBU/E			10	B,C,D,G	IR,	UV	IR	UV/IR
		3		2	B,C,D,G	IR,	UV	IR	UV/IR
				10	B,C,D,G	IR,	UV	IR	UV/IR
		4		0	B,C,G	IR,	UV		UV/IR
6	Roadway Light, Long	1	10	0	O				
	Low Pressure Sodium	2		2,10	O,O				
	50 x 35 W	3		2,10	O,O				
	L 70RB-35	4		0	O				
7	Roadway Light, Round	1	10	0	O				
	Mercury Vapoir	2		2,10	O,O				
	H309KB-175	3		2,10	O,O				
		4		0	O				
8	F-16 Landing Light	1	5	0	G				UV/IR
	GE 4581	2		2	B,G	IR,			UV/IR
				5	B,G	IR,			UV/IR
				10	B,G	IR,			UV/IR
		3		N/A	N/A				
		4		N/A	N/A				
9	F-16 Refueling Light	1	5	0	O				
	4C28 (Three)	2		2	O				
				5	O				
				10	O				
		3		N/A	N/A				
		4		N/A	N/A				
10	Small Incandescent Bulbs	1	5	0	O				
	1829 (Two)	2		2	O				
				5	O				
				10	O				
		3		N/A	N/A				
		4		N/A	N/A				
11	Work Light	1	5	0	O				
	Quartz Tungston Halogen	2		2	B,C,G	IR,	UV		
	(300 Watts)			10	B,C,G	IR,	UV		UV/IR
		3		2	A,B,C,E, H	UV/IR	UV/IR		
				10	A,B,C,D, E,F,G	UV/IR IR,,	UV,IR,	UV/IR	UV/IR .

Table 29 (Continued)

SOURCE NO.	SOURCE	TEST NO.	DISTANC FT.	CHOPPER hz	RESPONSE
					HIGH BEAM / LOW BEAM
12	Truck Headlight	1	5	0	G UV/IR G UV/IR / G UV/IR G UV/IR
	Incandescent Sealed Beam	2		2,10	
	GE 4811	3		N/A	
	High and Low Beam	4		N/A	
13	Flashing Strobe	1	5	0	0
	Light, Yellow	2		2,5,10	0,0,0
	Tandy 49-527	3		N/A	N/A
		4		N/A	N/A
14	Revolving Red Light	1	5	0	0
	Tandy 42-3040	2		2,5,10	0,0,0
		3		2,5,10	0,0,0
		4		0	0
15	Ultraviolet "Black"	1			
	Light	2		2	
	FE1T Electric			5	
	75A/BL			10	
		3		N/A	
		4		N/A	
16	Soft White Incandescent	1	5	0	0
	Lamp	2		2,10	0,0
	GE	3		N/A	N/A
		4		N/A	N/A
17	Crystal Clear	1	5	0	0
	Incandescent Lamp	2		2,10	0,0
	GE	3		N/A	
		4		N/A	
18	Workshop Light	1	5	0	0
	Dual Fluorescent	2		2,10	0,0
	Sylvania F-40	3		N/A	
	Rapid Start	4		N/A	
19	Hot Plate	1	?	0	0
	Hamilton Bech	2		2	D
	812-4			5	B,D,F(Yel IR, IR, IR
20	Hot Plate			10	B,D,F(Yel IR, IR IR
	Eastern Electric	3		N/A	N/A
	SB-101W	4		N/A	N/A
21	UV Bug Lamp	1	3	0	0

Table 29 (Continued)

SOURCE NO.	SOURCE	TEST NO.	DISTANC FT.	CHOPPER hz	RESPONSE
	BK-50	2		2,10	O,O
		3		N/A	N/A
		4		N/A	N/A
22	Flashlight, 2-cell	1	1	0	G,G UV/IR
	With Clear Lens	11	2	0	G UV/IR
	With Red Lens	3		0	G UV/IR
		4		N/A	N/A
23	IR Heating Lamp	1	5	0	O
	250 Watts	2		2	B,G IR, UV/IR
				5	B,D,G IR, IR UV/IR
				10	B,D,G IR, IR UV/IR
	COMBINATIONS				
1	TF 1 Lightall (MH)	1	12	0	G UV/IR
3	NF2D Lightall (HPS)	2		2,10	G,G UV/IR UV/IR
5	Round Flood (MH)	3		2	B,D,G IR, IR UV/IR
				10	B,D,G IR, IR UV/IR
		4			G UV/IR
2	NF2 Lightall (MV)	1	12	0	G UV/IR
3	NF2D Lightall (HPS)	2		2	B,G IR, UV/IR
5	Round Flood (MH)			10	B,C,G IR, UV UV/IR
		3			
		4			
1	TF Lightall (MH)	1	4,6	0	G UV/IR
2	NF 2 Lightall (MV)	2		2	B,D,G IR, IR UV/IR
3	NF 2 D Lightall (HPS)			10	B,D,G IR, IR UV/IR
4	Rectang. Flood (MH)	3		2	B,D,G IR, IR UV/IR
5	Round Flood (MH)			10	B,D,G IR, IR UV/IR
6	Roadway Long (LPS)	4			G UV/IR

Table 29 (Continued)

SOURCE NO.	SOURCE	TEST NO.	DISTANCE FT.	CHOPPER RPM	RESPONSE				
1	TF1 Lightall (MH)	1	8	0	G				UV/IR
2	NF2 Lightall (MV)	2		2	B,D,G	IR.		IR	UV/IR
4	Rectang. Flood (MH)			10	B,C,D,G	IR.		IR	UV/IR
3	NF2D Lightall (HPS)	3		2	B,D,G	IR.	UV	IR	UV/IR
5	Round Flood (MH)			10	B,C,D,G	IR.	UV	IR	UV/IR
6	Roadway Long (LPS)	4							
7	Roadway Round (MV)								
1	TF1 Lightall (MH)	1	10	0	G				UV/IR
2	NF2 Lightall (MV)	2		2	B,G	IR.			UV/IR
3	NF2D Lightall (HPS)			10	B,D,G	IR.		IR	UV/IR
4	Rectang Flood (MH)	3		2	B,D,G	IR.		IR	UV/IR
5	Round Flood (MH)			10	B,C,D,G	IR.	UV	IR	UV/IR
6	Roadway Long (LPS)	4			G				UV/IR
7	Roadway Round (MV)								
1	TF1 Lightall (MH)	1	12	0	G				
2	NF2 Lightall (MV)	2		2	B,D				
3	NF2D Lightall (HPS)			10	G				
4	Rectang Flood (MH)	3		2					
5	Round Flood (MH)			10					
6	Roadway Long (LPS)	4							
7	Roadway Round (MV)								
1	TF1 Lightall (MH)	1	18	0					
2	NF2 Lightall (MV)	2		2					
3	NF2D Lightall (HPS)			10					
4	Rectang Flood (MH)	3		2	B,D,G	IR.		IR	UV/IR
5	Round Flood (MH)			10	B,D,B	IR.		IR	UV/IR
6	Roadway Long (LPS)	4		0	G				UV/IR
7	Roadway Round (MV)								

Table 30
Response of OFDs to Sensor or Source Chopping

SOURCE NO.	SOURCE	TEST NO.	DISTANCE FT.	FREQUENCY Hz.	RESPONSE	
					OFD	OFD BANDS
3	High Pressure Sodium	1	25	0	O	
	1000 W Lucalox LU1000	2		2,10	O,O	
		3		2,10	O,O	
		4		0	O	
4	Metal Halide	1	25	0	O	
	MH250/U, 250W	2		2,10	O	
		3		2,10	O	
		4		0	O	
5	Metal Halide	1	25	0	O	
	MVR1500/HBU/E	2		2,10	C	
	1500W	3		2	C,D	UV,IR
				10	S,C,D	IR,,UV,IR
		4		0	C,D,G	UV,IR UV/IR
8	F16 Landing Light	1	25	0	O	
	GE 4581	2		2	B,C	IR,,UV
	450 W			10	B,C	IR,,UV
		3		N/A		
		4		N/A		
11	Quartz Tungsten Halogen	1	25	0		
	300 W	2		2	G	UV/IR
				10	C,G	UV,UV/IR
		3		2	C,F_{VIS}	UV
				10	C,F_{VIS}	UV
		4		0	C,F_{VIS}	UV
COMBINATIONS						
2	NF2 Lightall (MV)	1	25	0		
3	NF2D Lightall (HPS)	2		2,10	O,O	
		3		2	C,G	UV,UV/IR
				10	C	
		4		0	G	UV/IR
3	NF2D Lightall (HPS)	1	25	0	C	
5	Metal Halide 1500 W (MH)	2		2,10	C,O	
		3		2	D,G	IR,UV/IR
				10	D,G	IR,UV/IR
		4		0	O	

Table 30 (Continued)

SOURCE NO.	SOURCE	TEST NO.	DISTANCE FT.	FREQUENCY Hz.	RESPONSE	
					OFD	OFD BANDS
16	Soft White Incandescent	1	2.5	0	O	
	Lamp, GE 150 W	2		2	B,C,G	IR, UV,UV/IR
				10	B,C,G	IR,,UV,UV/IR
		3		N/A		
		4		N/A		
16	Soft White Incandescent	1	4	0	O	
	Lamp, GE 150 W	2		2	C,D,F^{YB},G	UV,IR
				10	C,D,F^{YB},G	IR,UV/IR
		3		N/A		
		4		N/A		
16	Soft White Incandescent	1	6	0	O	
	Lamp, GE 150 W	2		2	C G	UV,UV/IR
				10	C,G	UV,UV/IR
		3		N/A		
		4		N/A		
16	Soft White Incandescent	1	8	0	O	
	Lamp, GE 150 W	2		2	B,C,D	IR,,UV,IR
				10	B,C,D	IR,,UV,IR
		3		N/A		
		4		N/A		
16	Soft White Incandescent	1	10	0		
	Lamp, GE 150 W	2		2	B,C,D	IR,,UV,IR
				10	B,C,D	IR,,UV,IR
		3		N/A		
		4		N/A		
16	Soft White Incandescent	1	12	0		
	Lamp, GE 150 W	2		2	B,C,D	IR,,UV,IR
				5	B,C,D	IR,,UV,IR
				10	O	
		3		N/A		
		4		N/A		
17	Crystal Clear Incandescent,	1	10	0	O	
	GE 150 W	2		2	G	UV/IR
				10	B	IR,
		3		N/A		
		4		N/A		

Table 30 (Continued)

SOURCE NO.	SOURCE	TEST NO.	DISTANCE FT.	FREQUENCY Hz.	RESPONSE	
					OFD	OFD BANDS
17	Crystal Clear Incandescent,	1	14	0	O	
	GE 150 W	2		2	G	UV/IR
				10	B	IR.
		3		N/A		
		4		N/A		
17	Crystal Clear Incandescent,	1	16	0	O	
	GE 150 W	2		2	G	UV/IR
				10	B	IR.
		3		N/A		
		4		N/A		
17	Crystal Clear Incandescent,	1	18	0	O	
	GE 150 W	2		2	O	
				5	B	IR.
		3		N/A		
		4		N/A		
17	Crystal Clear Incandescent,	1	20	0	O	
	GE 150 W	2		2	O	
				5	G	UV/IR
				10	G	UV/IR
		3,4		N/A		
17	Crystal Clear Incandescent,	1	23	0	O	
	GE 150 W	2		2	G	UV/IR
				5	G	UV/IR
				10	O	
		3,4		N/A		
COMBINATIONS						
16	Soft White Incandescent	1	25	0	O	
17	Crystal Clear Incandescent	2		2	C,G	UV,UV/IR
				10	C,G	UV,UV/IR
		3		N/A		
		4		N/A		
16	Soft White Incandescent	1	4	0	O	
17	Crystal Clear Incandescent	2		2	C,G	UV,UV/IR
				10	C,G	UV,UV/IR
		3		N/A		
		4		N/A		

Table 31*

Response of OFDs to Sensor and Source Chopping and Small Successive Distance Increases

TEST NO. 1

SOURCE NO.	SOURCE	DISTANCE									
		5'	8'	10'	12'	14'	16'	18'	20'	22'	24'
1	MRV 1000/U	O									
2	H33GL - 400/DX	O									
3	LUCALUX - LU1000	O	O								
4	MH250/U	O	O								
5	MVR1500/HBU/E	O	O								
6	LZ0HB - 35	O									
7	H39KB - 175	O									
8	GE 4581	O	O								
9	4028-1 3 ca	O									
10	1829 2 ca	O									
11	131	O	O	O	O	O	O	O	O	O	O
12	SYLVANIA	O									
13	TANDY 49-527	O									
14	TANDY 42-3040	O									
15	75/VBL	O									
16	GE - SOFT WHITE	O									
17	GE - CRYSTAL	O									
18	F - 40 FLUORESCENT	O									
19	H.P. 812-4	O									
20	H.P. 58-101W	O									
21	BUG LITE DX-50	O									
22	2 CELL FLASH LITE	O(1)									
23	INFRARED LAMP	O									

* NOTE: Occurrence of F_{YEL} in data indicates that either the UV or IR sensor responded alone, not triggering the OFD fully on. Which sensor can only be deduced from the response of the other OFDs in the same measurement.

Table 31 (Continued)

TEST NO. 2: 2 Hz

SOURCE NO.	SOURCE	DISTANCE									
		5'	8'	10'	12'	14'	16'	18'	20'	22'	24'
1	MRV 1000/U	O									
2	H33GL - 4GO/DX	O									
3	LUCALUX - LU1000	B,G,F	C,G	C	O						
4	MH250/U	O	O	O							
5	MVR1500/HBU/E	B,C,D,G	B,C,D,G	B,C,D,G	G	O					
6	L70/B - 35	O									
7	H39KB - 175	O									
8	GE 4581	B,G	B,G	G,B	B,G	B,G	B,G	G	O		
9	4028-1 3 ea.	O									
10	1629 2 ea.	O									
11	T33	B,C,G	G	G	G	G	G	G	G	G	G
12	SYLVANIA										
13	TANDY 49-527	O									
14	TANDY 42-3040	O									
15	75A/8L	O									
16	GE - SOFT WHITE		B,C,D	B,C,D	B,C,D						
17	GE - CRYSTAL			G		G	G			G	
18	F - 40 FLUORESCENT	O									
19	H.P. 812-4	B,D,F_{wt},G	B,D,F_{wt},G	B	B	O					
20	H.P. SB-101W	B,D,F_{wt}	B,D,F_{wt}	B	B	B					
21	BUG LITE BK-50	O									
22	2 CELL FLASH LITE	G(1')									
23	INFRARED LAMP	B,G	G	G	G						

Table 31 (Continued)

TEST NO. 2: 10 Hz

SOURCE NO.	SOURCE	DISTANCE									
		5'	8'	10'	12'	14'	16'	18'	20'	22'	24'
1	MRV 1000/U	O									
2	H33GL - 400/DX	O									
3	LUCALUX - LU1000	B,G	G	O							
4	MH250/U	O	O	O							
5	MVR1500/HBU/E	B,C,D,G	B,C,D,G	B,C,D,G	B,G	G	O				
6	L70RB - 35	O									
7	H39KB - 175	O									
8	GE 4581	B,G	B,G	B,G	B,G	B,G	B,G	B,G	B,G	G	B
9	4028-1 3 ea.	O									
10	1829 2 ea.	O									
11	T33	B,C,G	G	G	G	G	G	G	G	G	G
12	SYLVANIA	G									
13	TANDY 49-E27	O									
14	TANDY 42-3040	O									
15	75A/BL	O									
16	GE - SOFT WHITE	B,C,D,F_{wL},G	B,C,D	B,C,D	O						
17	GE - CRYSTAL	O		B		B			G	O	
18	F - 40 FLUORESCENT	O									
19	H.P. 312-4	B,D,F_{wL}	B,D	B,D	B	O					
20	H.P. SB-101W	B,D,F_{wL}	B,D	D,B	B,D	B					
21	BUG LITE BK-50	O									
22	2 CELL FLASH LITE	G(2")									
23	INFRARED LAMP	B,D,G	B,D,G	B	O						

Table 31 (Continued)

TEST NO. 3: 2 Hz

SOURCE NO.	SOURCE	DISTANCE									
		5'	8'	10'	12'	14'	16'	18'	20'	22'	24'
1	MRV 1000/U	O									
2	H33GL - 400/DX	D,G	O								
3	LUCALUX - LU1000	G,B	G,B	B,G	G	O					
4	MH250/U	B	O								
5	MVR1500/HBU/E	B,C,D,G	B,C,D,G	B,C,D,G	B,C,D,G	B,C,D,G	B,C,D,G	G	O		
6	L70/B - 35	O									
7	H39KB - 175	N/A									
8	GE 4581	N/A									
9	4028-1 3 ea.	N/A									
10	1829 2 ea.	N/A									
11	T33	A,B,C,E,H	G,C,E,F_{HL}	C,E,F_{HL}	C,F_{HL}	C,F_{HL}	C,F_{HL}	C,F_{HL}	C,F_{HL}	C,F_{HL}	C,F_{HL}
12	SYLVANIA	N/A									
13	TANDY 49-527	O									
14	TANDY 42-3040	O									
15	75A/BL	N/A									
16	GE - SOFT WHITE	N/A									
17	GE - CRYSTAL	N/A									
18	F - 40 FLUORESCENT	N/A									
19	H.P. 912-4	N/A									
20	H.P. SB-101W	N/A									
21	BUG LITE BK-50	N/A									
22	2 CELL FLASH LITE	G(2')									
23	INFRARED LAMP	N/A									

Table 31 (Continued)

TEST NO. 3: 10 Hz

SOURCE NO.	SOURCE	DISTANCE									
		5'	8'	10'	12'	14'	16'	18'	20'	22'	24'
1	MRV 1000/U	O									
2	H33GL - 40C/DX	B,D,G	B,D,G	B,D	B,D	B	O				
3	LUCALUX - LU1000	B,D,G	B,G	B,G	B,G	O					
4	MH250/U	B,G	O	O							
5	MVR1500/HBU/E	B,C,D,G	B,C,D,G	B,C,D,G	B,C,D,G	B,C,D,	B,C,D,G	B,D,G	B,D,G	G	G
6	L70RB - 35	O									
7	H39KB - 175	N/A									
8	GE 4581	N/A									
9	4028-1 3 ea.	N/A									
10	1829 2 ea.	N/A									
11	T33	A,B,C,D,	C,E,F_{WL}	A,E,F_{WL}	C,F_{WL}	C,F_{WL}	C,F_{WL}	C,F_{WL}	C,F_{WL}	C,F_{WL}	C,F_{WL}
12	SYLVANIA	N/A									
13	TANDY 49-527	O									
14	TANDY 42-3040	O									
15	75A/BL	N/A									
16	GE - SOFT WHITE	N/A									
17	GE - CRYSTAL	N/A									
18	F - 40 FLUORESCENT	N/A									
19	H.P. 812-4	N/A									
20	H.P. SB-101W	N/A									
21	BUG LITE BK-50	N/A									
22	2 CELL FLASH LITE	G(2')									
23	INFRARED LAMP	N/A									

Table 31 (Continued)

TEST NO. 4

SOURCE NO.	SOURCE	DISTANCE									
		5'	8'	10'	12'	14'	16'	18'	20'	22'	24'
1	MRV 1000/U	O									
2	H33GL - 400/DX	O									
3	LUCALUX - LU1000	O									
4	MH250/U	O									
5	MVR1500/HBU/E	G	G	G	G	O					
6	L70/B - 35	O									
7	H39KB - 175	N/A									
8	GE 4581										
9	4028-1 3 ea.	N/A									
10	1829 2 ea.	N/A									
11	T33	C,E,G	C,E	C,E,F_{rel}	C	C	C	C	C	C	C
12	SYLVANIA	N/A									
13	TANDY 49 527	O									
14	TANDY 42-3040	O									
15	75A/BL	N/A									
16	GE - SOFT WHITE	N/A									
17	GE - CRYSTAL	N/A									
18	F - 40 FLUORESCENT	N/A									
19	H.P. 812-4	N/A									
20	H.P. SB-101W	N/A									
21	BUG LITE BK-50	N/A									
22	2 CELL FLASH LITE										
23	INFRARED LAMP	N/A									

detector. The phase relationships may also play a part in reducing signal flux. Each detector, therefore, can be expected to have its own "irradiance versus distance" set of curves unique to itself. This becomes demonstrated to some degree in the data of Tables 29 through 31.

Comparing these tables with chopped data against that of Table 25 with unchopped data, it becomes evident that the straight flux from either AC or DC operated radiation sources is not sufficient, in general, to trigger all detectors. However, where the source flux is chopped, the detectors are triggered to false alarm. Response of the detectors, at least those used in these tests, is therefore controlled by the particular frequency response "window" designed into the detector.

Since this is not a study of the devices themselves, but of the capability of relevant radiation sources to trigger false alarms in existing devices, the body of data developed here can help detector designers achieve improvements in their devices. Also, these data can help Air Force facility and operations designers and managers to determine what types of sources of UV and IR, and their locations, would be allowed, and disallowed, in hangars and shelters.

Before addressing the question of how the data summarized above gives indication that the concept in question is valid, one other experimental determination is made. This is the question of how much UV radiation is given out in the primary 200 nm band of interest by certain sources when the protective window is on or off. Only the 200 nm band photomultiplier sensor, the most sensitive of all the instruments used in this study, was used for this determination. Table 32 gives the data for six radiation sources of practical interest.

As is shown in Table 32, the difference is indicated as being relatively small, although, as will be shown later, there is a pronounced effect on detectors to alarm when the glass cover plate is removed or cracked/broken. The implication is that radiation in the 200 nm UV band is not reduced greatly by the protective window, but rather by the outer bulb of the lamp itself, if it has one. If the outer bulb, however, were to crack or rupture, the UV radiation emanating from the lamp would be much greater than normal. Examples of such circumstances, where a small hole or crack occurred in the outer bulb, could enhance the probability of a false alarm event. At least one such event has been identified as being caused by such a cracked outer bulb.

D. EXAMPLES OF POTENTIAL FALSE ALARMS FROM THE PRESENCE OF MULTIPLE NONFIRE SOURCES OF UV AND IR RADIATION

1. Simple Two-Source Test

Analysis showed that the potential of false alarms is much greater when two or more UV and/or IR radiation emitters are present in the FOV of a detector and that the sources have enough radiance in the detector's operating spectral bands to equal or exceed the Air Force Criteria irradiances at the distance of the detector. A standard 300-watt Quartz Tungsten Halogen (QTH) work lamp, with its glass cover plate on, has an irradiance in the 185 nm to 250 nm band at about 30 feet distance which is equivalent to a 2-foot x 2-foot JP-4 pan fire at 100 feet in the same spectral band. This means that this lamp alone, located at 1 - 30 feet from the detector, may satisfy the UV irradiance threshold value required by a fire detector to alarm, provided other factors (e.g. flicker), if any, are also satisfied.

Table 32

Comparison of UV Exitances from Sources
With and Without Their Protective Window

(Distance = 22")

SOURCE NO.	SOURCE	WITH WINDOW $\mu W/cm^2$	WITHOUT WINDOW $\mu W/cm^2$	PERCENT INCREASE
1	METAL HALIDE LAMP MVR 1000/U	5.16E-2	5.39E-2	4.5%
2	MERCURY VAPOR LAMP H33G1-400/DX	3.22E-2	3.91E-2	21.4%
3	HIGH PRESSURE SODIUM LAMP H33GL-400/DX	5.23E-2	5.26E-2	0.57%
4	METAL HALIDE LAMP MH 250/U	4.76E-2	4.90E-2	2.9%
5	METAL HALIDE LAMP MVR 1500/HBU/E	5.23E-2	5.48E-2	4.8%
11	QUARTZ TUNGSTEN HALOGEN T-33	4.95E-2	5.04E-2	1.8%

If the detector is a multi-wavelength detector, also requiring satisfaction of a 4.4 μm band IR threshold, this same lamp projects an irradiance out to about 30 feet distance that equals or exceeds that emanating from the 2-foot x 2-foot JP-4 pan fire at 100 feet. Therefore, a single source may satisfy dual wavelength detection requirements, at least as far as the irradiance values are concerned.

Again, other factors have been built in to most detectors today that add features such as "flicker," ratioing, or intensity

"spikes". These "other" factors can also be duplicated and are not "foolproof." For example, the chopping effect can be duplicated by several people walking in front of a source, a person waving his arms, an irregularly shaped vehicle or mobile platform being moved between the detector and source, a fan, or the chopping effect inherent in certain light sources when they are in start, restart, or failure modes. In some cases, the chopping effect, or flicker frequency requirement built into the detector's response logic, has a narrow frequency window. As an example, it will not alarm unless the frequency is 10 Hz or more, while another detector will respond if the frequency is anywhere between 1 Hz and 20 Hz.

If a detector did not require chopping or some other effect, the detector would assuredly false alarm if its spectral irradiance threshold(s) were satisfied. If the detector required the additional factor of "flicker" (1-20 Hz UV and/or IR signal variation, or other factors) to be satisfied, then the detector should not "go-off" to this simple light source, unless all requirements, including spectral irradiance and flicker and other factors, were satisfied. We test this hypothesis below.

One of the simplest scenarios to be found in an aircraft hangar or shelter would involve a hot body, such as a vehicle's exhaust, an AGE exhaust manifold and engine, an aircraft engine nozzle, heater, etc. and a light source such as a 300 watt incandescent Quartz Tungsten Halogen lamp. Both types of sources are found routinely in Air Force hangars/shelters and maintenance docks. Assume that the detector is mounted on the side wall, 10 feet above the floor to provide underwing coverage, and the optical axis of its FOV is pointed at a 45° angle to the floor.

Assume the presence of a common piece of Aircraft Ground Equipment (AGE), a TTU 228/E Hydraulic Test Stand Unit. This unit has an inside exhaust pipe temperature in the 670° C (1238° F) range, and an exposed exhaust stack/pipe surface with a temperature of 367° C (694° F). Assume that this AGE item is located 20 feet from the detector, which would be normal in a standard Hardened Aircraft Shelter Series 1-3. The irradiance of this "hot body" in the 4.4 micrometer band is such as to exceed the irradiance from a 2-foot x 2-foot JP-4 pan fire as far away as 100 feet.

Also, for purposes here, assume the Quartz Tungsten Halogen lamp is without its glass cover plate, and is 10 feet away from the detector, located on an adjacent wall near the front door of the hangar in the FOV of the detector (note that 1000 watt lamps of this type are sometimes used in large maintenance hangars and 1500 watt to 6000 watt versions are often used for internal facility photography). Broken glass cover plates on lamp fixtures is not rare and in some facilities lamp fixtures may be without their glass cover plates.

Because it is impractical to locate a TTU 228/E Hydraulic Test Stand AGE unit in the lab, a simple 1000-watt hot plate can be used for simulation. A single-element hot plate at full power will reach about 670° F, almost half the temperature of the AGE interior exhaust pipe and about the same as the exhaust pipe surface. Also, its areal extent is about half of that of the AGE exhaust surface. At 10 feet, this hot plate has about the same irradiance in the 4.4 micrometer band as does the 1238° F AGE unit at 15-20 feet. Therefore, we have chosen to locate the simulator hot plate at 10 feet distance, along with the 300 watt lamp, for this representative test.

To test whether different types of detectors would alarm to the simultaneous presence of these nonfire radiation sources, located at distances from the detectors which emulate practical situations, the following test was conducted using the array of 8 fire detectors. This test procedure would be one of many required of the manufacturer to prove detector immunity and reliability before the Air Force took delivery of the detectors.

Step 1. Turn on the detector and let it warm up for a few minutes to verify that it is working properly. After 10 minutes, turn-on the 1000 watt hot plate at maximum. After 10 minutes at maximum temperature, observe the response of the detectors.

Step 2. "Chop" the IR-emitted radiation from the hot plate with a "chopper blade" apparatus such as the fan-wheel device described earlier and in Appendix II, at speeds of 1 Hz to 10 Hz and above. This duplicates several people walking in between the hot plate and detector, a floor fan, an irregularly shaped vehicle passing through the FOV, or a person waving his arm in front of either the detector or hot plate. Observe the response of the detectors.

Step 3. Remove the hot plate or let it cool down to room temperature and then turn on the Quartz Tungsten Halogen lamp with the glass cover plate on. Observe the response of the detectors. After 15 minutes turn lamp on and off at 10 second intervals, 5 times. Observe the response of the detectors.

Step 4. Chop the radiation from the lamp by the same means as above, either by waving an object back and forth through the FOV close to the lamp or with the use of a fan by just spinning the fan blade by hand.

Step 5. Turn the hot plate back on and let it reach maximum temperature. Ten minutes after it has reached maximum temperature, turn on the lamp. Observe the response of the detectors over the next 10 minutes.

Step 6. Chop the hot plate's emission with the lamp remaining on and not chopped. Observe the response of the detectors. Turn off the lamp. While the hot plate is being chopped, switch on the lamp. Observe the response of the detectors.

Step 7. Stop chopping the hot plate and chop only the lamp. Observe the response of the detectors.

Step 8. Chop both sources near the detector so that the entire FOV is chopped. Observe the response of the detectors.

Step 9. Repeat steps 1-8 with the Quartz Tungsten Halogen glass plate cover removed.

Table 33 summarizes the response of the different detectors to these nine steps. Note that the response for steps 1-8 are given first in the table as "Y" or "N" (yes or no response), followed by another "Y" or "N" designating the response to step 9 when the lamp glass cover plate is removed. Light fixtures without glass cover plates are not uncommon, as are also cracked or broken lens cover plates.

What occurs is as follows:

In Step 1 no responses are observed, implying that its irradiance at 10 feet distance is either less than that from a 2' x 2' JP-4 pan fire at 100 feet, and/or all other detection criteria, such as flicker/chopping, are not satisfied.

In Step 2, detectors B and D go off to both glass cover plate-on and glass cover plate-off conditions, both detectors being IR detectors. This implies that the irradiance in the IR <u>is</u> equivalent to that from a 2' x 2' JP-4 pan fire at 100 feet and that, indeed, chopping is a requirement of these IR detectors. Other detectors did not go off because no UV was present.

In Step 3, no detectors alarm when the glass cover plate is on, indicating that the UV irradiance is either insufficient and/or other conditions such as chopping have not been met. But with the glass plate removed, detectors C and E alarm when the lamp is turned on, and detectors C, E, and G alarm when the lamp is switched on and off consecutively. Detector C is a UV-only detector and E and G are dual UV/IR units, indicating that the IR from the lamp is equivalent to that from a 2' x 2' JP-4 pan fire at 100 feet.

In Step 4, only detector G goes off when the glass cover plate is on and the radiation chopped. This same detector also alarmed in Step 3 above without chopping and without the glass plate cover. This indicates that the chopping effect is not very important to this detector. Detectors A, C, and E alarm without the glass plate on the lamp. Detectors A and E therefore have IR thresholds that are satisfied by the lamp.

In Step 5, detectors C and G are the only ones to alarm with the glass plate on. Without the cover plate, detectors C, E, and G respond.

In Step 6, detectors B, C, D, and G alarm with the glass cover plate on. Without the cover plate, detectors A, B, C, D, G, and H go off. This indicates the importance of IR chopping to these detectors.

In Step 7, no detectors go off with the cover plate on. However, without the cover plate, detectors A, C, E, and G go off.

Table 33

False Alarm Response Due to Presence
of Hot Body and 300 W Quartz Tungsten Halogen Lamp

TEST #	SOURCE & CONDITION	DETECTORS A UV/IR	B IR	C UV	D IR	E UV/IR	F UV/IR	G UV/IR	H UV/IR
1	HOT PLATE-ALONE	NN	NN	NN	NN	NN	NN	NN	NN
2	HOT PLATE CHOPPED	NN	YY	NN	YY	NN	NN	NN	NN
3	QTH LAMP-ALONE NO HOT PLATE	NN	NN	NN	NN	NN	NN	NY	NN
4	QTH LAMP-CHOPPED NO HOT PLATE	NY	NN	NY	NN	NY	NN	YY	NN
5	HOT PLATE + QTH LAMP: UNCHOPPED	NN	NN	YY	NN	NY	NN	YY	NN
6	HOT PLATE CHOPPED AND QTH LAMP UNCHOPPED	NY	YY	YY	YY	NN	NN	YY	NY
7	HOT PLATE UN-CHOPPED AND QTH LAMP CHOPPED	NY	NN	NY	NN	NY	NN	NY	NN
8	BOTH HOT PLATE AND QTH LAMP CHOPPED	NY	YY	YY	YY	NY	NN	YY	NY

In Step 8, detectors B, C, D, and G go off with the glass plate on. All detectors except F go off when the glass cover plate is removed.

The results of Step 9 indicate that either an additional amount of UV in the 185-250 nm band must be present, and/or shorter wavelength UV, previously absorbed by the glass plate, may be present that has higher ionization efficiency of the UV tube's gas fill. Lamp fixtures such as the one used here are sometimes found with cracked or broken lenses, or without the entire glass cover plate.

The overall results indicate the importance of chopping the IR and UV emissions. Although chopping may not be an important factor for some detectors, and not a factor at all for others, it still affects the various mechanisms of all the detectors used herein.

Analysis of this table demonstrates the various requirements, in addition to sufficient energy flux in different spectral bands, to cause a detector to alarm. It is apparent from Steps 1 and 2 that the IR-only detectors employed here require some form of chopping along with sufficient spectral irradiance to alarm. Also, from steps 3 and 4, it is apparent that the UV-only detector does not require chopping of the UV radiation source, as it will go off without the glass plate cover with or without chopping.

These tests were repeated several times to determine consistency of detector response. The only variation in the repeated tests was a slight change in the frequency of the chopper wheel device. It was observed that this small change, in some cases, affected a detector's response.

It appears that, in general, the 300-watt Quartz Tungsten Halogen lamp with its glass fixture plate on meets, or is slightly less, than the average detector's specific spectral irradiance requirements at 10 feet distance in the UV band(s) of interest, and certainly meets or exceeds these requirements when the glass cover plate is removed/broken. It must be remembered, however, that with the chopper operating the energy flux incident upon the detector is reduced by 50%. The relative distance then of the source from the detector is much larger than the 10 feet used here. Also, the internal electronics of the detector also has an effect upon the relative distance of the source.

The irradiance of the lamp without the cover plates was measured to be about 5.04×10^{-2} microwatts/cm^2 at 22 inches distance. This equates to an irradiance in the 200 nm band of about 1.69×10^{-3} microwatts/cm^2 at 10 feet distance, the distance used here in these procedure tests. This lamp source, if located 34 feet from the detector, without its glass cover plate, would therefore have the same irradiance in this spectral band as a 2'x 2' JP-4 pan fire at 100 feet. This shows the large difference in irradiance-effective distance when an incandescent or HID lamp fixture is

without its glass cover or if the cover is cracked or broken.

As pointed out above, the chopping effect imposed in these tests, by its very nature, reduced the irradiance of UV and IR, respectively, by as much as 50%. This implies that the actual irradiance levels during chopping can be correlated with the same sources located at greater distance than the 10 feet used herein.

It can therefore be concluded from this simple procedure that optical fire detectors, in general, can be fooled by the presence of certain nonfire types of sources of UV and IR, and especially if other factors are present such as objects of motion that may effectually "chop" (disrupt) the UV and/or IR signals at a frequency between 1 Hz and 20 Hz.

The testing of multiple sources according to prescribed test procedures is discussed in Section VII, and recommended test procedures are listed in the specification in Appendix II.

2. Tests with Multiple Sources

The last part of Table 29 lists several tests with multiple combinations of sources, of various types. These tests were patterned after typical aircraft hangar and shelter layouts and operational scenarios. In these tests only AGE support equipment light sources and area lights of the HID type were included, no hot bodies and no fluorescent or incandescent lights. These lights themselves are dual emitters of both UV and IR, the IR emanating from the element, inner and outer bulbs, and fixture/glass cover as the lamp heats to maximum temperature.

The same detectors were used in these tests to determine general responses when two or more sources were present within the detector's FOV. Note that in these tests, only detector G responded without the presence of chopping, and detectors B, C, D, and G responded with chopping, "G" being the only dual UV/IR detector to respond. The distances of these sources from the detectors was varied between 5 and 18 feet with basically the same response at each distance increment. The reason the UV/IR detectors did not respond with an alarm to these <u>particular</u> combinations is probably because these specific lamp sources do not produce near the heat (IR), and therefore the necessary irradiance in the 4.4 micrometer band at the distance of the detector, as do incandescent lamps such as Quartz Tungsten Halogen, as demonstrated earlier.

E. PRELIMINARY INDICATION OF CONCEPT VALIDITY

It is beyond the scope of this program to cover the many examples in the data that could be used to verify the predictability of false alarm triggering range for each radiation source, and for each detector. However, a few cases are selected

here for illustration of what can be done to obtain such information.

First, two strong light sources, and the two standard 150 watt incandescent bulbs, are used to discuss their theoretical "irradiance versus distance" curves in relation to the empirical study of their triggering range of the detectors. The question is: how well do the theoretical curves fit the experimental data? If the fit is not good, does the difference indicate what the reason may be?

Basic to the procedure used here is to establish what is being defined in this study as the "Air Force Criterion." Since the requirement given to detector manufacturers is that their device must be able to detect a "2 foot x 2 foot JP-4 pan fire at 100 feet," and not false alarm, implicit in this requirement is the irradiance that such a fire produces and transmits to the 100 foot distance. What this irradiance is in the particular spectral wavelengths or bands of interest has not ever been defined or included in any fire detector specification or purchase description. Yet these spectral irradiance values are the crux of any fire detector's performance.

A few irradiance values have been experimentally determined in this study, but more such measurements should be made. As cited above, it can be expected there is a spread of values, since each pan fire burn can behave differently. However, a statistical value should be obtainable that can be used here in this procedure.

Since the three bands of interest used here were chosen on the basis of current detector exploitation of the UV and IR fire characteristics, an "Air Force Criterion" was established experimentally for each band. The JP-4 pan fire measurements made in the 200 nm, 254 nm, and 4.37 micrometer bands provided maximum and minimum values for the 200 nm and 4.37 micrometer bands, and one value for the 254 nm band.

The reason for using both the 200 nm and 254 nm bands is that they overlap somewhat, and, since it is not known precisely what are the spectral response characteristics of each UV sensor, information for both bands was obtained. The overlap may vary depending upon several factors such as the ionization tube's gas type(s) and mixtures, envelop material (usually quartz glass), and electronics (such as gating). For instance the bell-shaped response curve of the detector may have a sharp on-set at 185 nm, peak at about 220 nm, and then drop off rapidly to 240 nm. At this point, however, it "tails-off" almost exponentially out to 280 nm and more.

The detector thus has some response sensitivity, although low, to fire-produced or nonfire produced UV in this longer wavelength band area where considerable UV flux may occur from many sources.

If this flux in the longer wavelength band is significantly greater than that in the lower wavelength detection band of about 185 nm - 240 nm, the detector will respond. Therefore, it is important that this intermediate UV band be considered in addition to the main "200 nm - centered band."

Hence, on this basis, the "Air Force Criteria" values are given in Table 34.

Table 34

Air Force JP-4 Triggering Irradiance Criteria

	200 nm band microwatts/cm^2	254 nm band microwatts/cm^2	4.37 micron band microwatts/cm^2
maximum:	1.40 E -4	2.21 E -1	2.59 E 1
Minimum:	3.89 E -5	-	1.47 E 1

The next question is: at what threshold distances from the lamps being considered here would the irradiance from each lamp be just equal to the Air Force Criterion for each band? This will be answered in two ways: (1) for the full flux from the source, and (2) for half the full flux from the source. As has been discussed above, the curves given in Figures 37 through 43 are based on the full flux values. The half flux values are due to the 50% duty factor of the irradiance chopper used in some test procedures.

These values are summarized in Table 35. Since it is not clear at this point whether the half flux values, or even smaller values due to frequency or other effects in the detectors, should be used, curves are not determined accordingly at this point.

Using the values in Table 35, the distances at which there would be irradiance values just equal to the Air Force Criterion values are summarized in Table 36. It must be kept in mind the maximum and minimum values used in Tables 35 and 36 are based on the Air Force Criteria values. A "min" value is a lower irradiance triggering requirement, and therefore a nonfire radiation source can be farther away and still provide the irradiance to trigger a false alarm. Hence, the seeming contradiction in Table 36 is due to this fact that min values of the Air Force Criteria have larger threshold triggering distances than the max values.

Now comparing Table 36 with the relevant experimental values in Tables 29, 30, and 31, it is seen that, to the extent the limited laboratory distance verification allowed, the experimental

values in Tables 29, 30 and 31 are consistent with the values in Table 36. Table 36, however, indicates greater distances than were available in the laboratory, which are particularly necessary for investigating combinations of radiation sources. On the other hand, Tables 29, 30 and 31 indicate shorter threshold distances than Table 36, which may imply other unknown factors about the detectors' operations.

The experimental data extracted from Tables 29, 30 and 31 that summarize the investigation of the four light source irradiances as a function of distance are given in Table 37.

Table 37 experimentally helps confirm Table 36. Study of the two tables shows that Table 37 is incomplete in checking what Table 36 indicates can be the threshold distances for the AF Criteria.

With further investigation, this concept may prove very useful. What it indicates at this point is that it might be possible to use as simple a source as the 150 watt soft white lamp at proper and relatively short distances to simulate the "Air Force Criteria" for any type of fire, of any size, at any distance, within any time. The curves point to this possibility.

The one lamp, however, that turned on all the detectors was the 300 watt Quartz Tungsten Halogen lamp with its window off and chopped at 10 Hz. As a radiation source that is capable of doing this, it also could be made to function as an Air Force Criteria simulator.

Table 35

Comparison of Air Force Criteria Irradiances at 100 Feet and Possible False Alarm Source Exitances at 0 Feet

		200 nm $\mu W/cm^2$	254 nm $\mu W/cm^2$	4.37 μm $\mu W/cm^2$
I. Air Force Criteria (at 100 Feet)				
	Maximum:	1.40E-4	2.21E-1	2.59E1
	Minimum:	3.89E-5		1.47E1
II. Metal Halide Lamp MVR 1500/HBU/2 1500 Watts				
Exitances:	Full:	1.87E-1	8.60E2	5.96E4
(at Source)	Half:	9.35E-2	4.30E2	2.98E4
III. Quartz Tungsten Halogen Lamp T-33 300 Watts				
Exitance:	Full:	1.78E-1	3.50E2	5.19E4
(at Source)	Half:	8.90E-2	1.75E-2	2.59E4
IV. Soft White Incandescent Lamp GE 150 Watts				
Exitance:	Full:	1.33E-1	3.13E1	6.68E3
(at Source)	Half:	6.65E-2	1.57E1	3.34E3
V. Crystal Clear Incandescent Lamp GE 150 Watts				
Exitance:	Full:	1.58E-1	1.76E1	8.27E3
(at Source)	Half:	7.90E-2	8.80E0	4.14E3

Table 36

Threshold Distances at Which Candidate False Alarm Source Irradiances Just Satisfy Air Force Criteria

CONDITIONS		THRESHOLD DISTANCES 200 nm FT.	254 nm FT.	4.37 μm FT.
I. Metal Halide Lamp MVR 1500/HBU/E 1500 Watts				
Full Flux:	Max:	33.09	61.63	43.37
	Min:	58.21		55.91
Half Flux:	Max:	24.04	43.73	31.52
	Min:	43.07		40.91
II. Quartz Tungsten Halogen T-33 300 Watts				
Full Flux:	Max:	32.35	39.49	40.72
	Min:	57.00		52.58
Half Flux:	Max:	23.49	27.99	29.52
	Min:	42.14		38.39
III. Soft White Incandescent Lamp GE 150 Watts				
Full Flux:	Max:	28.31	11.87	15.49
	Min:	50.27		20.33
Half Flux:	Max:	20.49	8.41	11.67
	Min:	37.00		14.57
IV. Crystal Clear Incandescent Lamp GE 150 Watts				
Full Flux:	Max:	30.64	8.91	17.70
	Min:	54.16		22.51
Half Flux:	Max:	22.22	6.30	12.29
	Min:	39.97		16.16

Table 37

Examples of Experimental Data Supporting the Concept

	TEST NO.	CHOP. FREQ	5'	8'	10'	12'	14'	16'	18'	20'	22'	23'	24'	25'
I. Metal Halide	1	0	G		BCDG									O
Lamp 1500 W	2	2	BCDG	BCDG	BCDG	G	O							O
		10	BCDG	BCDG	BCDG	BG	G	O						O
	3	2	BCDG	BCDG	BCDG	BCDG	BCDG	BCDG	G	O				GCD
		10	BCDG	BCDG	BCDG	BCDG	BCDG	BCDG	BDG	BDG	G			GBCD
	4	0	G	G	BCG	G								CDG
II. Quartz Tungsten	1	0	G	G	G	G	G	G	G	G	G	G		
Halogen 300 W	2	2	BCG	G	G	G	G	G	G	G	G	G	G	
		10	BCG	G	G	G	G	G	G	G	G	G	CG	
	3	2	ABCEH	CEF_vG	CEF_v	CF_{VII}	CF_{VII}	CF_{VII}	CF_{VII}	CF_{VII}	CF_{VII}	CF_{VII}	CF_{VII}	
		10	ABCD EFGH	ACE F_vGH	AEF_v	CF_{VII}	CF_{VII}	CF_{VII}	CF_{VII}	CF_{VII}	CF_{VII}	CF_{VII}	CF_{VII}	
	4	0	CEG	CE	CEF_{VII}	C	C	C	C	C	C	C	CF_{VII}	
III. Soft White	1	0												
Incandescent	2	2	$BCDF_vG$	BCD	BCD	BCD								
150 W		5				BCD								
		10	$BCDF_vG$	BCD	BCD	O								
	3,4	N/A												
IV. Crystal Clear	1	0												
Incandescent	2	2			G	G	G			G			G	
150 W		10			B	B	B	B	B	G			G	
	3,4	N/A												

Since almost all of the radiation sources studied show their "irradiance versus distance" curves in Figures 37 through 43 cross the Air Force Criteria lines, any one of them whose curves do so in all three bands could be used to function as such a simulator. This would need further verification. This also shows how the curves assist in making a decision regarding a simple, practical simulator for test purposes. Checking the choice against the experimental results in Tables 29, 30 and 31, it can be seen whether the choice is supported by such data.

The concept of making exitance measurements of candidate false alarm sources in the bands of interest and then computing and plotting their irradiance curves as a function of distance, provides an important tool for deriving information about the threshold distances at which the curves just cross the Air Force Criteria lines. In so doing, a false alarm may be triggered. To know this is to have an insight and understanding into the behavior of the sources and sensors, and to be able to predict that a false alarm will, can or did happen in any scenario, and to reduce if not eliminate the problem.

Its further study and application are recommended as a promising technique for improving progress toward greater fire detector reliability and false alarm immunity, especially for current UV and IR detectors. The concept has been outlined here in a skeletal manner. Its full study shows promise, even with the limited evidence available at this preliminary stage.

SECTION VII

QUALIFICATION TEST PROCEDURES

A. INTRODUCTION

The previous sections described the nature and properties of sources of UV and IR radiation in the same, or near, spectral regions of hydrocarbon fire emissions, and where fire detectors operate. Also described were several experiments to test the hypothesis that individual and/or combinations of sources, located at distances from a detector that emulate the irradiances of a 2-foot x 2-foot JP-4 pan fire at 100 feet, the design threshold fire size/distance, should cause a detector to alarm, provided all detection requirements have been met. It was shown that a fire detector will alarm to a UV/IR source as simple as a Quartz Tungsten Halogen lamp when its radiation is interrupted at frequencies of 1 Hz to 20 Hz.

However, it was also shown that dual UV/IR detectors are much more difficult to confuse than straight single channel IR or UV detectors, even when they require other factors to be present such as chopping or ratioing. Although not discussed, it was also found that some of the detectors alarmed when the distance was varied between a lamp source and a hot body source, or when the lamp source was moved in the FOV. These detectors were not predictable in their overall performance.

Realizing that many different scenarios can be constructed which involve different types of UV and/or IR emitters, and that many types of operations can occur within a hangar or shelter environment, it is then prudent to determine the false alarm immunity of a fire detector before it is installed in an operational mode.

Because there are many types of fire detectors that may be considered in various applications, test procedures should be general enough to cover all types and varieties, including all types and varieties of false alarm sources.

This section describes false alarm immunity qualification tests procedures which could be included within a fire detector purchase description or performance specification.

B. BACKGROUND AND NEED

A review of the Navy Safety Center and Air Force Inspection and Safety Center records of reported false alarm events, or false activations of fire protection systems, indicates a rather large variety of possible causes, including the category "unknown."

These causes range from aircraft engine start-ups, aircraft engine exhausts, welding, hot bodies, lightning, lamps, ground equipment/vehicle engines/exhausts, tools, electromagnetic radiation, ionizing radiation, and many other sources. Other causes relate to environmental factors such as vibration, shock, salt water immersion, and electrical failure.

The causes can thus be categorized as follows:

CATEGORY 1. Lights (sources that emit in any spectral band of the UV, visible, or IR).

a. Fixed in-place lights for facility, hangar, shelter, runway, ramp, area, and building illumination.

b. Moving lights such as those on vehicles (fire trucks, security cars, ambulances, personnel carriers, towing trucks, and fuel trucks.

c. Photographic lights.

d. AGE (Aircraft Ground Equipment) area lighting carts ("Lightalls").

e. Aircraft lights such as landing, IFR, and collision avoidance lights.

f. Tools such as flashlights with colored lens covers.

g. Insect repellant lights (black lights).

CATEGORY 2. Reflected light (either UV, visible, or IR).

a. Reflected from colored objects, clothing, standing fluids, sand, ground, runway, glass, and polished metals, regardless of source.

CATEGORY 3. Natural Phenomena.

a. Sunlight.

b. Lightning.

CATEGORY 4. Electrical Arcing/Electrostatic Discharge.

a. High voltage arcing such as from power transformers, motors, faulty wiring, and

electrical devices.

b. Electrostatic discharge to detector.

CATEGORY 5. Nondestructive Investigative (NDI) Devices.

a. X-ray machines up to 300 KeV. Although OFDs do not operate in the x-ray region, certain types of detectors, such as UV vacuum tubes which operate as ionization counters, are directly affected. Also, certain solid-state electronics may be affected by x-rays.

CATEGORY 6. Electromagnetic Waves.

a. Portable radio communication devices such as "Walkie-Talkies", cellular phones, and remote telephones.

b. Radar emissions from aircraft.

c. Emissions from electronic switching power supplies and electronic equipment.

d. Emissions from aircraft subsystems such as communications jammers, decoys, and other weapon-system-associated items.

CATEGORY 7. Aircraft Engine Emissions (UV, visible, IR).

a. Any emission of UV, visible, or IR radiation from the engine exhaust during start-up, engine power settings through 80% (military), and during afterburner operation.

CATEGORY 8. Personnel Items.

a. Lit cigarette/cigar.

b. Matches (paper and wood).

c. Butane lighter.

CATEGORY 9. Tools/Operations.

a. Arc, TIG, and MIG welding operations.

b. Acetylene welding/cutting operations.

CATEGORY 10. Hot Bodies, Blackbody Radiators, Rapid Changes in Air Temperature.

a. Hot manifolds, exhausts, radiators, mufflers, and engines of all types of vehicles.

b. Hot manifolds, exhausts, radiators, and mufflers on AGE (aircraft ground equipments).

c. Thermal treating blankets.

d. Aircraft heaters/blowers.

e. Aircraft brakes, engine nozzles, pods.

f. Radiation heaters (1.5 KW and 1.0 KW with fan).

g. Radiation kerosene heater, 70,000 BTU, with fan.

h. Hot lights, lamps, welding materials (included in Categories 1 and 9).

CATEGORY 11. Security/Military Personnel Weapons.

CATEGORY 12. Fire/Explosive Events Associated with Aircraft and AGE Engine Wet Starts/Backfires.

These sources and modulators of UV, visible, and IR radiations, either by themselves or in combinations of two or more, may be causes of false alarms to some detectors. Testing therefore, for OFD false alarm immunity to the presence of these radiation stimuli either individually or in multiples, is required.

A separate category of possible false alarms is related to the performance reliability of the detector in regard to its operation in a specified environment. Military Standard Mil-Std-810 (latest edition) specifies the various environmental factors and test procedures to be followed in verifying a detector's reliability when exposed to such factors as temperature, pressure, shock, vibration, water, humidity, salt, fog, and fungus, all of which may affect a detector's performance.

The answer to the question, "Is there a need to verify a detector's or a full detection system's immunity to such a broad list of possible causes of false alarms?" resides with the procurer or user of the detector(s). Not only must the performance be based upon the fire threat, but also the detector's reliability must be based upon the environment to which it will be exposed. There are

two reliabilities then that are important: (1) reliability to detect the specified fire threat, and (2) reliability to not false alarm. These two reliabilities comprise the Mission Success Reliability and relate to quality of the components (mean time between failures - MTBF), and ability to discriminate against nonfire sources, thus maximizing the detector's "time available to detect fire" and minimizing "fire protection system down time."

A fire protection system is an integral part of the survivability and readiness of a weapon system. Its function is to assure the safety and, therefore, the availability of the weapon system to meet its mission objective. It should therefore be viewed in the same light as any other weapon system component that plays an integral part in the weapon's (e.g. aircraft) operation. All components of a weapon system, including peripheral parts and supporting subsystems, must conform to the overall performance and reliability specification of the system as a whole. The fire protection system then should be considered integral to the success of military aircraft operations and to the safeguarding of valuable assets. The higher the reliability of the fire detectors in meeting the above dual mission success criteria, the higher will be the mission success reliability of the aircraft. A fire detection system charged with the responsibility to protect a $40 million aircraft, or a $1 billion B-2, should obviously be proven to meet the fire detection and nonfire alarm immunity requirements before it is installed for operational purposes. Verification, then, of these performance characteristics can be just as important in fire detection as it is in purchasing a component for the aircraft.

Because there are many diverse applications of fire detectors and many possible situations involving complex and multiple sources of UV, IR, and visible radiations that may simulate some of the spectral characteristics of fire, it would be prudent to develop a set of optional qualification test procedures which such fire detectors should be required to pass. The first set would be the performance criteria which relates to the ability of the detector, or detection system, to detect a fire of specified size, type, and distance location, within a specified maximum time. This specification would be developed by the user agency for the specific application. Along with this specification would be the requirements of quality and reliable performance while exposed to certain environments, such as temperature, vibration, shock, water, salt, fungus, EMI, and other factors. This type of specification is currently required by the Army for fire protection systems on fighting vehicles, and by the Air Force on aircraft to protect engine, APU, and drybays. It seems reasonable to require the same type of performance specification for fire detectors mounted inside hangars and shelters to protect the overall aircraft system from exterior fire.

The second set of qualification test procedures would be used

to establish proof that a detector would not false alarm to the types of complex nonfire sources of radiations that may be in the field of view of the detector at any time. This second set of qualification test procedures is addressed herein.

C. BASIS OF THE TEST PROCEDURES

The criteria established for the test procedures was as follows:

1. The sources of radiation must either be the actual sources which the detector would be exposed to, or simulations of the source that produced the same, or nearly the same, radiation flux.

2. The distances, and therefore irradiance values, chosen for the location of the sources relative to the detector's location and FOV, must be representative of actual configurations, physical layouts, and operations within the FOV of the detector. However, worst case scenarios should be considered to cover all possible situations, including those that may involve violations such as open cigarette lighter flame, or even welding or x-raying within the vicinity.

3. The procedures should be adaptable to the requirements of the user agency, depending upon the application.

4. The tests should be easy to conduct and repeatable.

5. The test results should be unequivocal and easily interpreted.

6. The cost to conduct the tests should be low; if possible, inexpensive simulations should be used where practical.

7. Qualification by similarity, analysis, and simulation should be allowable if the manufacturer can demonstrate the equivalency of such means to the recommended test procedures.

8. The qualification test procedures for false alarm immunity should also be conducted in conjunction with performance specification tests to assure that the detector will meet

the fire detection requirements while also in the presence of the stipulated false alarm source or sources. This would require simultaneous exposure to fire and potential false alarm sources.

9. Other qualification tests related to military standards may also be required to prove reliability and performance according to the specification of the user/buyer. These mil-standard certifications would be cited by the user/buyer and would possible include Mil-Std-810, Mil-Std-461, Mil-Std-462, and Mil-Hdbk-217. These are discussed further in Appendix II.

D. SIMULATIONS

There are many possible false alarm sources and operations that may affect optical fire detectors (OFDs). Many of these sources and operations are impractical to locate and conduct in a laboratory environment. For example, lightning, aircraft engine exhaust, aircraft engine in afterburner mode, exhaust manifolds and pipes/structures of AGE items and vehicles, and wet start or backfire "fire" events associated with some AGE items and aircraft. These objects and phenomenon can be simulated in the lab with fairly simple UV and IR sources.

Hot bodies can be simulated using Calrod heating elements or single and dual element 1000 W electric hot plates. The temperature of a hot plate can be varied until its radiance in the 4.4 μm band is equivalent to that of the possible false alarm source at some specified distance.

Also, in the ultraviolet, a standard deuterium lamp can be used such as the Oriel 6006 lamp used in this study. With an appropriate narrow band photomultiplier, in the 185 nm - 250 nm band, or other spectral regions, the irradiance can be adjusted to satisfy the test requirements.

Other simulations are necessary for aircraft engine exhausts and afterburner effluents. Again, both an infrared heat source and a UV source can be used to conduct this simulation. Appendix II discusses the irradiance values that would have to be simulated.

In situations where it may be impractical to obtain large wattage HID lamps, smaller HID wattage lamps may be used but placed closer to the detector to attain the same irradiance value as called for in the test specification. When 2 or more identical lamps are required, such as associated with one of the AGE Lightall units, only one lamp may be employed, and placed, again, at a closer distance to emulate the appropriate irradiance value.

Instead of a sophisticated chopper apparatus to chop the radiation between the source and the detector, a simple fan could be used as long as its chopping frequency could be determined and varied, and its duty cycle known. A strobe could also be used to determine the rotational frequency and a variable power supply could be used to vary the speed. Whatever process is used to simulate radiation beam interruption at frequencies between 1 Hz and 20 Hz, the percent of time of the "on" and "off" cycles should be known so that the reduction percentage in the radiation flux can be estimated and the distance of the source compensated.

Most of the UV sources are easily obtained. Some, such as intense photographic lights and welding apparatus, can be rented.

Tests that involve electromagnetic waves and ionizing radiation may have to be conducted in a certified testing facility. This is normally done when Mil-Std-461 is called out in the performance specification. The possible presence of radar, jamming device, and communication system activations in the presence of an OFD may require certain qualification tests to be performed. The power density of a high frequency navigation radar beam may reach 50 or more volts per meter standing field at large distances, and could affect a detector's electronics.

Weapon discharges may not be easily simulated, but, should the types of weapons specified not be easily available, a conventional automatic rifle and shotgun and a starting pistol may suffice.

Sunlight may also be simulated by a solar light simulator such as a filtered Xe lamp. These are readily available from many optical suppliers.

In general, the detector manufacturer may choose to qualify its detector in ways different than outlined in Appendix II. This is appropriate as long as approval is obtained from the user or purchasing agency.

E. SELECTION OF FALSE ALARM TYPES AND CONFIGURATIONS

The basis of selecting the types of possible false alarm sources for these test procedures was developed from firsthand observation of many Air Force hangars and shelters throughout the U.S. and Europe; analysis of reasons for past false alarm events based upon data obtained from the Air Force Inspection and Safety Center, the Navy Safety Center, AF base ground maintenance and support personnel, and the detector manufacturers themselves; and analysis of spectral emission characteristics of various objects and phenomena that might exist in the vicinity of a fire detector. Obviously, it would be impossible to identify all possible false alarm sources and their configurations. It is also obviously out of the question to require qualification tests on each and every independent source and every combination of possible sources that

may exist in the application. Although it may seem duplicative to test a smaller wattage lamp when a larger wattage lamp will also be present, the fact is that both lamps must be tested at the same time because the irradiance at the detector is an addition of the spectral irradiances of each. For example, it may seem imprudent to require a detector response test to a 400 W mercury vapor lamp if the detector would also be exposed to a 1000 W mercury vapor lamp at a distance which would exceed the irradiance of the smaller lamp at its closest distance. However, it must be remembered that it is the maximum spectral irradiance in specific bands that must receive prime attention when determining requirements for qualification tests.

Worst-case, yet real situation, scenarios were selected where practical, rather than requiring a large number of less rigorous tests first. If the worst case scenario did not result in a detector false alarm, the less stringent tests were eliminated. On the other hand, if the worst case test resulted in an alarm, then other tests could be called for.

It was also found in analyses of hangar and shelter configurations that there was no established uniformity in the types of lamps used, their relative positioning, or their integrity (i.e., some without glass cover plates). In some USAFE (European) and NATO bases, banks of fluorescent lights are often used. Also, large HID-types of lamps may be mounted at the floor level which can be pointed from vertical-up to 90° normal to the wall. In many flow-through hangars, standard 300 W Quartz Tungsten Halogen lamps are used, some with broken fixture lenses. Because of this wide disparity of lamps, as well as other types of false alarm sources including heater types, equipment, aircraft, operations, and other items, it is necessary to include all types of possible false alarm sources in the qualification test procedures. It is then up to the user or purchasing agency to determine the specific tests that are applicable to its needs.

F. DEVELOPMENT OF TEST PROCEDURES

The approach taken in the development of test procedures delineated in Appendix II was to categorize possible sources of detector false alarms, and then evaluate each in terms of its potential effects, if any, on all types of fire detectors, including UV, IR, visible, multiple spectral response, thermal, and temperature rate-of-rise. Smoke detectors were not considered.

Spectral emission properties, including other physical, temporal, and spatial characteristics, were then analyzed for each and tabulated for reference purposes (in this volume and in Appendix I).

Test procedures were then formulated for single sources and multiple sources, including operations that may cause time, intensity, and spectral perturbations of the source's emissions. These test procedures were then modified to fit expected applications and situations in which the detector could possibly be engaged.

These test procedures were then carried out in the laboratory, if feasible, to verify that they could be conducted and that definitive conclusions could be deduced. Sources and detectors were mounted on mobile platforms for the purpose of modifying relative distances and in simulating motion of vehicles and aircraft.

Eight fire detectors were used, consisting of 2 IR detectors, 1 UV, and 5 UV/IR. As stated earlier in this report, these detectors were used only to verify that some or no response resulted from the test, and to substantiate that a source (or phenomenon) produced the expected spectral irradiance and/or effect on the detector's logic. Other detectors used were the assemblage of UV and IR measurement devices used to determine the emission characteristics of objects during the program.

Tests were repeated several times to determine consistency of experimental technique. Although it was deemed important to have repeatable results, several detectors were not 100% consistent in their responses. The reason for this discrepancy was attributed to the various factors imbedded in the detector's "fire decision logic." In some cases, however, no apparent reason could be found for a detector's alarm when it had previously not alarmed during the same test. Because of this discrepancy it was deemed prudent to require these qualification tests to be conducted/repeated several times.

G. RESULTS

The proposed test procedures are included in Appendix II. This document has been prepared in the format of a military specification which could be included with an RFP (request for proposal), PD (purchase description), or Performance Specification. The document is not a panacea of false alarm tests, but a selected number of tests that cover, in general, those projected applications of fire detectors.

The specification needs to be further developed and tailored to the needs of the agencies having requirements for its use. This is especially true of the scenarios involving several types of potential false alarm sources and operations.

SECTION VIII

CONCLUSIONS

A. OVERVIEW

This study met its objectives of characterizing the nature and properties of objects, phenomena, and operations that may have some influence on the operation of a fire detector to alarm to the presence of a fire when no fire exists. It also met its objectives in prescribing tests that, if conducted, would qualify a detector's performance against the possible sources of false alarms that it may be exposed to in a specific application.

The results support the previous Phase I feasibility study (Reference 48) and the past detector false alarm studies conducted during the Hardened Aircraft Shelter Fire Protection System development and test program (Reference 49)

Detectors were employed in this study for the sole purpose of assisting in the development of qualification test procedures and in helping to verify expected effects from certain types of false alarm sources. Although the detectors responded differently to some of the tests, no attempt was made to compare one detector's performance to another's. Rather, the different responses helped to indicate the different phenomena that may affect a fire detector's logic.

In general, the number of false alarms and false activations of suppressant systems due to optical fire detector's lack of immunity to nonfire sources of UV and IR, is much less today than it was several years ago. The advent of the dual UV/IR detector, with the subsequent added features of required flicker frequency, ratioing, time gating, and/or intensity variation have greatly improved the reliability of fire detection. But problems still exist and will continue to exist as long as these fire detection logic features can be satisfied by extraneous nonfire causes, such as shown herein.

The intent of this effort, to further enhance the reliability of present fire detectors by providing a "test basis" on which to verify their immunity to the possible objects and phenomena that may affect their performance, was therefore met. Its implementation requires both Air Force action and industrial support. These tests are not only useful as "check points" but as a help to the manufacturer to identify potential problems in advance and to develop additional discrimination means to alleviate the possible false alarm problem.

B. SPECIFIC CONCLUSIONS

This study resulted in the following conclusions:

1. Optical fire detectors can and do respond to nonfire UV and/or IR stimuli and, with the necessary conditions satisfied, will false alarm.

2. Objects and phenomena that emit UV and IR radiation in the same spectral bands as does a hydrocarbon fire, and in the same spectral bands where optical fire detectors operate, are commonly found in hangars/facilities within a detector's FOV and detection sensitivity range.

3. Optical fire detectors that operate in dual UV and IR spectral bands, and require several factors to be satisfied in the overall fire decision logic process, are less likely to "false alarm" to nonfire sources than single wavelength detectors, regardless of what additional features monowavelength band detectors may employ.

4. A "chopping" or cyclic time variation of either the UV and/or IR radiation is a common detection logic feature of the majority of optical fire detectors today. It was found that without this chopping/flicker frequency variation feature, most detectors would false alarm easily, although even with this feature some detectors are affected by any modulation of the IR beam. This fact is evident by (1) the demonstrated poor performance of older single wavelength band UV or IR detectors which were, and in some cases still are, installed in Air Force and Air National Guard hangars/shelters; and (2) by the experimental results obtained in this study. Most detectors require some form of flicker in the frequency range of 1 - 10 Hz.

5. The chopping or flicker frequency requirement can be simulated by motion of objects between the source and the detector or, in some instances, by the source itself during its start-up or restart process. The shorter the time period over which chopping must continue before the logic process is satisfied, the higher the potential of the detector

responding to a nonfire type of interruption/ variation. On the other hand, by extending the time period to make the detector less sensitive to spurious nonfire motions/flicker, the more time a fire has to develop and the greater is its threat. This is especially a problem if one of the major fire threats is a moving stream of fuel which has been ignited. The fire front moves at about 10 - 12 ft/sec and, therefore, by extending the detection process time only one second, the under-aircraft fire could result in major damage before the detector alarmed.

6. A detector's "time-to-alarm" from the instant the fire has reached the specified threshold size should be as short as possible to minimize damage, but long enough to minimize false alarms. This is one dilemma with UV and/or IR optical fire detectors. It is less of a problem for slow evolving fires than for fast reacting events which can occur in aircraft drybays and engine bays, weapons storage facilities, and pyrotechnic manufacturing facilities. In these latter applications a detector must operate in less than 1 second and a "flicker" frequency detection requirement cannot be used, therefore increasing the detector's false alarm sensitivity.

7. Although the frequency of occurrence of optical detector false alarms has decreased over the past few years, the number of Air Force hangars, shelters, and other facilities without any form of such fire detection protection is still widespread. In fact, several locations still have "old technology" detectors that have been disconnected and awaiting replacement with current technology units. The Air Force's plan to upgrade these systems with more advanced and reliable fire detectors will substantially decrease false alarms, providing some of the precautions and recommendations herein are adopted.

8. There are few shelters such as the Hardened Aircraft Shelter Tab V Series 1-3 variety, that contain optical fire detection systems. These types of facilities, which involve complex, multiple aircraft,are most likely to be associated with objects and phenomena that

may affect the detection reliability of optical fire detectors.

9. In addition to nonfire UV, visible, and IR stimuli associated with false alarms, other factors such as operational environment, affect a detector's reliability and therefore its performance and life. Vibration, temperature, humidity, salt, shock, x-rays, and high frequency electromagnetic emissions may affect the detector's operation. Several past false alarms were attributed to water inside the detector housing, water inside the detector's electronic controller, breakage of an electronic component or circuit by engine vibration, or large standing electric fields due to communications systems. These problems could be minimized by imposing military standards such as Mil-Std-810 and Mil-Std-461, as well as other quality assurance standards such as quality military parts, workmanship, and manufacturing (such as Mil-Q-9858). Such standards are routinely imposed on fire detectors and fire suppression systems by the Army for all fighting and support vehicles, and by the Navy and Air Force for aircraft and helicopters, respectively.

10. Lights are the most common type of potential false alarm sources. High-intensity discharge lamps and incandescent lamps are basic emitters of UV and IR radiation in the two spectral bands of interest, namely, 185 nm - 250 nm, and 4.2 μm - 4.7 μm. Such lights are commonly used for illumination inside and outside of facilities and for photographic use.

11. Another very common source of 4.4 μm band IR radiation is from hot surfaces such as engine exhausts and manifolds, aircraft engine nozzles and exhaust effluent, hot lamps, Aircraft Ground Equipment (AGE) units (engine surfaces and lights), photographic equipment, metal surfaces during welding or cutting, personnel heaters, facility heaters, and thermal blankets.

12. Although there are many types of sources of both UV and IR radiation in the spectral bands where fire also emits, the energy flux, or spectral radiance, may not be sufficient to

affect a detector even at close distances. However, the more sensitive a detector is set to detect smaller fires at greater distances in less time, the greater the distance one of these nonfire radiation emitters can be to affect the detector.

13. For purposes of this study, the Air Force fire threshold specification of a 2-foot x 2-foot JP-4 pan fire at 100 feet distance from the detector was adopted as the detection performance requirement. This means that any detector, regardless of spectral type and the number of spectral bands used in its operation, must be able to measure spectral irradiances in all its spectral bands of operation, which equal or exceed those from a 2-foot x 2-foot JP-4 pan fire located at 100 feet distance. At this threshold requirement, it was found that there are many types of false alarm sources that satisfy these irradiance values, some at distances exceeding 100 feet.

14. The most predominant false alarm sources that satisfied irradiance values in either or both UV and IR bands at large distances from the detector were welding and cutting operations, aircraft engines in the afterburner mode, very hot exhaust pipes and exposed engine surfaces, hot heater elements, kerosene heaters, large wattage HID lamps, and incandescent lamps. Most of these objects were involved in the past in false alarm events.

15. There were no major surprises in locating unexpected nonfire sources of UV and/or IR radiation in the bands of interest. However, it was found that the simplest of lights, the incandescent lamp, was one of the major sources that by itself could produce sufficient irradiance to fool a detector. A high wattage white frosted bulb or a Quartz Tungsten Halogen lamp are potential sources of false alarms.

16. It was found that when the glass cover plates were removed from HID and incandescent lamp fixtures, that detectors responded more readily at greater distances than when the cover was in-place and the lamp was located closer. This increased detection response was

attributed to two possibilities: (1) less absorption and therefore increased flux of the lower wavelength, and more efficient ionizing UV radiation below 190 nm, and (2) more flux in the 185 nm - 250 nm band due to less absorption media. Although the increased irradiance in the band 185 nm - 250 nm was typically small when measured with the lens cover off, the effectual distance of the source was increased markedly. The removal of the plate did not affect the detection response of the detectors in the IR band. Evidently, the IR irradiance was not reduced or was not reduced enough.

17. The most probable false alarm situation involves the presence of several UV and/or IR sources at the same time, as well as motion between the sources and detector and/or the movement of one of the sources itself. The operations and objects within a Hardened Aircraft Shelter or other operational aircraft hangar/shelter comprise the largest threat to false alarms. On the other hand, the presence of only one single source in any situation may be sufficient to cause a detector or any type to false alarm. For this reason, qualification test procedures to prove detector immunity must cover an in-depth list of possible sources as well as a complete-as-possible list of multiple and complex operations.

18. In the field measurements of spectral irradiances from JP-4 fires of various pan sizes at distances up to 100 feet, it was found that the irradiance values differed from one test to another, depending upon factors such as wind and humidity (atmospheric transmissivity). The minimum and maximum values were used in the analyses performed herein. In all cases the maximum value was used in comparing relative irradiances with nonfire sources and their relative distances. This was the most conservative approach to take in evaluating possible false alarm sources. It was also found that atmospheric transmission must be taken into account when analyzing the data for irradiance values in both the UV and IR.

19. A technique was developed that would enable the determination of the possibility of false

alarm events due to the presence of an emitter of UV and/or IR radiation. Given the detection specifications for the fire type, size, and distance, the "minimum spectral irradiance" values in the UV and/or IR bands of interest are then known. The detector must therefore be able to measure these "minimum" irradiance levels to guarantee that it will "see" the fire anywhere from 1 foot to the maximum distance specified.

Once these irradiance thresholds are known for all the spectral bands in which the detector operates, e.g., UV and IR, it is then necessary to determine what nonfire sources of radiation in these same wavelength bands may be present within the FOV of the detector. It is then necessary to determine at what maximum distance from the detector must these nonfire sources be located to provide an irradiance in the UV and/or IR that is equal to or greater than from the JP-4 fire at 100 feet. Knowing the irradiances at one distance is sufficient to determine them at other distances using the inverse square law and atmospheric absorption corrections. These values can then be compared at the distances between detector and sources as planned by the user. If the configuration is such that the spectral irradiances from the nonfire sources are equal to or greater than those from the design threshold fire at that distance, then a potential false alarm situation exists.

It was concluded that such a model would be very advantageous to both the user agency acquiring the detectors and the detector designer/manufacturer. In those cases where a possible false alarm situation may exist, the user agency can either change the configuration, forbid certain operations to occur while the detectors are on, require the detectors to be turned off when certain operations may be in process, or require the manufacturer to meet the false alarm immunity requirement by a detector design change.

Regardless of the option chosen, it was concluded that it would be beneficial to both parties to prove detector false alarm immunity by completing qualification tests that covered all the possible conditions for false alarms.

20. It was concluded that the test procedures specified herein are attainable and would demonstrate the ability of a detector to discriminate against nonfire sources of UV, visible, and IR radiation.

SECTION IX

RECOMMENDATIONS

A. GENERAL DISCUSSION

This study provided detailed insight into the problem of optical fire detector false alarms and the nature and properties of the objects and phenomena that cause them. As a result of the effort, which included field measurements, laboratory measurements, literature reviews, analysis of historical records, and analytical derivations, two products evolved. The first is a model which can be used to ascertain whether certain possible objects/phenomena, whatever their distance from the detector, can satisfy the detector's radiation detection threshold. The second is a qualification test procedure specification which can be used as part of the procurement process by the detector user or purchasing agency to verify fire detector immunity, reliability, and performance against possible false alarm sources before the detector is acquired. The scope of this project did not allow for a thorough development of these products. They are therefore limited to some degree in their extent and application and need further expansion, refinement, and test.

The project involved many facets of fire chemistry and physics, detector technology, spectroscopy, optics, and spectral emissions from a vast number of objects. A rather large number of field and laboratory measurements and JP-4 and AV-A burn tests were conducted. Although significant amounts of data were acquired, a considerable amount of additional data and analysis are needed tc fully complete this undertaking to the appropriate technical depth.

B. SPECIFIC RECOMMENDATIONS

From the conclusions discussed previously in Section VIII, and from other considerations referenced in this report and its Appendices, there are several recommendations to the Air Force that should be implemented. These recommendations are as follows:

1. The preliminary model (herein referred to as "False Alarm Model"), to determine if a UV and/or IR emitter, either alone or in combination with others, could be a possible cause of false alarms due to its spectral irradiance at some distance from the detector, should be developed further and more thoroughly tested. The specific tasks that should be accomplished are:

a. Higher resolution measurements should be made of the spectral irradiance of 1 ft^2, 4 ft^2, 16 ft^2, and 100 ft^2 square JP-4 and other fuel (diesel, gasolene, etc.)pan fires at distances up to the maximum distance the Air Force may specify in a fire detection performance specification (e.g., 50 feet, 100 feet or more). These spectral measurements should be made with a medium resolution spectrometer from 185 nm through about 400 nm in the UV, through the visible, and in the IR, especially from 1 μm to 5 μm. Burns should be made, if possible, in a no-wind environment.

b. While in the process of these JP-4 fuel burn tests, it would be prudent to also conduct hydrazine and other hydrazine compound fuel burns to obtain their spectral irradiances from the near UV, through the visible and out to about 5 μm in the IR. There is no spectral irradiance data today for hydrazines, although fire detection of such types of fires is becoming more and more important to the Air Force. The only data that exist are "relative" intensity spectra in some parts of the UV and IR for only a few hypergolic substances.

c. UV spectral emissions/irradiances from aircraft jet engines during power settings of idle through afterburner should be measured. Very little useful data now exist. This is especially true in the 185 nm - 250 nm band where fire detectors are most sensitive in the UV. No attention in the past has been given to UV afterburner emissions.

2. When the Air Force, either independently or in conjunction with the Army Corps of Engineers or any other agency solicits quotations/ proposals for fire detectors and fire detection systems, a detailed list of possible

false alarm sources which would be present within the FOV of the detector, should be included. Also, minimum distances of each source from a detector should be quoted along with the maximum spectral irradiances expected at the detector at any time during the application. This would include consideration of multiple sources which would be present simultaneously and their additive spectral irradiances in the specific detection bands of interest. By supplying both the maximum spectral irradiance values and the list of sources of UV, IR, and visible radiation, the manufacturer could choose the technique to conduct qualification tests. He would have the option of simulating the specific spectral irradiances with an appropriate spectral source, employing the exact list of objects as part of the tests, or using a combination of each.

4. The spectral irradiance values for the fuel fire type, size, and distance should be minimum values. Using minimum values for the fuel spectral irradiances and maximum values for the possible false alarm spectral irradiances is the most conservative approach. It will guarantee worst case scenarios.

5. Along with the above list of sources, distances, and irradiances, a qualification test procedures specification should be included which specifies certain tests to be performed which correspond to the list of sources and their distances provided above. This specification should request certification that the proposed detector(s) or detection system passed the required false alarm immunity tests.

6. The qualification test procedures specification proposed herein should be reviewed by the appropriate Air Force fire protection organizations for clarity, completeness, and accuracy. It should then be reviewed by the detector manufacturers for their comments and recommendations. Care should be taken to assure that the specification is "all inclusive" of the many types of applications, detectors, objects and phenomena that may be considered by the user and/or procurement agency.

7. The Air Force should not allow any type of HID or incandescent lamp with a broken/cracked or absent glass cover plate to be located in any hangar, shelter, or maintenance facility that contains optical fire detectors.

8. It would be prudent to replace any single channel UV or IR detectors as soon as possible with more "fool proof" detectors.

9. Detectors, controllers, and fire protection systems in general, purchased for military use to protect any valuable asset, weapon system, or military operation, whatever the application, should be required to conform to the environmental specifications of Mil-Std-810 and Mil-Std-461 and-462 as a minimum.

10. Coordinated "tri-service" performance and false alarm test procedures specifications should be developed. The Army already has a military standard document and the Air Force and major aerospace aircraft manufacturers have partial specifications. Although the requirements and applications may differ somewhat between the Departments, the false alarm qualification tests should be the same, at least in process. The potential false alarm sources may differ depending upon the application but their types and characteristics will be virtually the same.

11. This project did not include the analysis and testing of "systems" per se. A fire detection system operates in a different manner than a single detector and adds reliability against false alarms. In almost all cases of past false alarms, single detectors were at fault and few if any fire detection systems were involved, or for that matter, even existed. A requirement can be built into the detection logic that requires 2 or more detectors to cover the same floor area and 2 or more detectors to "vote" (detect) the fire and have other detection factors satisfied before the "system" activates the discharge of the suppressant. It is recommended that all future fire detector procurements for new construction or for refurbishment of facilities, be for an entire system, and that single detectors or stand-alone detectors now installed in Air Force hangars and shelters be

replaced as soon as possible with "systems" using the most up-to-date advanced technology detector having the maximum false alarm immunity.

12. The Air Force should encourage and financially support the development of new fire, explosion, and smoke detector concepts that will not false alarm to UV or IR emissions. The following Air Force needs should be addressed:

(1) Detection and alarm of hangar, shelter, and facility fires immediately when a fire of 1-2 square feet occurs at any location, and automatic release of suppressant when the detector determines the fire to be equal to or greater than the threshold specified size/threat.

(2) As an added feature to (1), determination where the fire is located. This will allow selective and discretionary "zonal" release of fire suppressant such as halon in systems now installed and will minimize environmental impact and at the same time save cost.

(3) In addition to (1) and (2) above, determination of the distance of the fire. This will allow automatic ranging of fire fighting and crash rescue vehicle turret-released suppressant when the vehicle reaches maximum range. It would also allow for selective discharge of extinguishers or linear arrays in aircraft located closest to the fire.

(4) Detection within 10-20 miliiseconds or less of rapid developing explosive-type events in aircraft drybays and munitions and weapons storage facilities.

(5) Development of a false alarm proof engine bay/nacelle fire detector with pilot-in-the-loop video confirmation.

(6) Development of a hydrazine, UDMH, MMH, and Aerozine-50 fire detector. This device would be beneficial at Cape Canaveral and at other AF locations using such fuels. Efforts to modify hydrocarbon fire detectors to this application have not been successful to date.

All these detector needs require the highest degree of false alarm immunity.

13. When conducting any false alarm immunity test involving a chopper device, consideration should be given to the fact that, depending upon the on/off chopper cycle and its rotational frequency, the energy from the emitting source will be greatly reduced at the face of the detector. This, in essence, makes the effective distance of the source from the detector much greater than the physical distance. Also, any gating in the detector's electronic detection mode must be considered relative to the rotational on/off time of the chopper wheel.

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